

# SPACE SCIENCES LABORATORY

## AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA USING REMOTE SENSING TECHNIQUES

A report of work done by scientists  
of 6 campuses of the University of  
California. (Davis, Berkeley, Santa  
Barbara, Los Angeles, Irvine, and  
Riverside) under NASA Grant  
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## PREFACE

The urgent need to manage earth resources wisely generates, in turn, a need to inventory them accurately. As a prerequisite to intelligent management, the earth resource manager must know, for each component of the earth resource "complex", how much of it is located in each portion of the area which he seeks to manage, i.e., he must have an "integrated" inventory. Since May, 1970 remote sensing scientists on 6 campuses of the University of California have been engaged in a NASA-funded project which seeks to make an integrated study of the entire resource complex for one of the three areas which have been selected by NASA as primary test sites for earth resource surveys, viz. the state of California.

Many of the earth resource components in California, as in most other parts of the world, are dynamic rather than static. Therefore, it is necessary for these resources to be inventoried frequently and rapidly -- frequently so that resource trends can be followed -- rapidly so that resource management decisions can be made and implemented while the inventory data are still current. Our present studies, based largely on NASA-flown photography, are giving major emphasis to such considerations. These studies give particular consideration to the opportunities that will soon be afforded for satisfying these requirements through a combination of human and machine processing of ERTS-A data acquired (weather permitting) every 18 days.

The wise management of earth resources in an area such as the state of California depends, however, on far more than the mere acquiring of

timely, accurate resource inventories. Even when given such information, the resource manager could easily make wrong decisions if he were to ignore certain important socio-economic factors. Alternately stated, human needs and emotions cannot be overlooked (particularly in these days of the environment "crusaders") as we seek better to manipulate earth resources, whether on a local, regional, national or global basis.

As will be indicated in the present progress report, due consideration is being given to each of the foregoing factors in this "integrated" study.

Robert N. Colwell  
Principal Investigator  
December 28, 1971

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## Chapter 1

### INTRODUCTION

Early in 1969 the Director of NASA made a statement, somewhat as follows, to the Director of the NASA-funded Space Sciences Laboratory of the University of California: "In addition to the research which your laboratory is already doing for NASA in such fields as planetary physics and systems analysis, it would seem desirable for you to consider doing work which is related to NASA's Earth Resources Survey Program".

This statement led to a series of planning sessions, participated in by faculty representatives from all of the major campuses of the University of California. The scientists prepared several remote sensing proposals dealing with topics which ranged from the global monitoring of volcanic eruptions to the study of aerosols in the atmosphere. Among these was a proposal to conduct an integrated study of California's entire "resource complex" through remote sensing from aircraft and spacecraft.

Of these various proposals, only the latter led to funding by NASA, the first allocation of funds having been made in May, 1970. From the outset, half of these funds have been contributed by the NASA Earth Resources Survey Program and half by the NASA Office of University Affairs, but with a substantial amount of matching support provided by the University of California.

Since its inception this study has been given the rather cumbersome

but aptly descriptive title: "An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques". Reasons for selecting the state of California for the test site included the following:

1. It exhibits a great variety of earth resources, landforms and climatic factors.
2. Large amounts of remote sensing data and associated ground truth data already are available for many parts of California.
3. With respect to earth resource management, various social and environmental stresses already are being felt strongly, making California a model of things to come, both nationally and globally.
4. Many competent investigators were known to be residing in California and available for assignment to such an integrated study. In fact several of them had been performing research under the NASA-funded Earth Resources Survey Program almost since its inception in the mid-1960's.
5. Appropriate NASA-funded facilities which had already been established in California (such as the Space Sciences Laboratory on the Berkeley campus of the University of California, and the NASA Ames Research Center near Sunnyvale, California) were known to be available to provide administrative and monitoring support, as necessary, for any sizeable integrated study that might be conducted within the state.

#### 1.1 NATURE AND "DELICACY" OF THE STUDY

It was recognized in our proposal to NASA that little would be accomplished under this integrated study if we attempted to investigate, at the outset, all components of California's entire earth resource

complex, statewide. Ideally we would begin our study by investigating some discrete phase of this complex which, although of limited scope, would require a consideration of both the resource interrelationships and the attitudes of the people in a very sizeable part of the state. Given these constraints and ambitions we tentatively selected the "California Water Project" as the focal point for this initial phase of our study. The word "tentatively" is used advisedly because it was recognized that resource managers and administrators, particularly within the Administrative Branch of the state of California, would need to be consulted in order to determine (1) whether such a study would meet with their favor or disfavor and (2) whether, in the event that we were authorized and funded to conduct such a study, mutually beneficial working relationships with resource managers in the Administrative Branch might be developed.

Initially there were some serious reservations expressed by certain personnel in the Administrative Branch as to the advisability of our conducting any study, whatsoever, that might relate specifically to the California Water Project. They pointed out that most of the decisions that were required both in conceiving and in developing the California Water Project already had been made long before our study was proposed. We were well aware of this fact and had been regarding it as a major strength rather than a weakness in our proposed study, since our objective was not to provide a "critique" of either the concept that resulted in authorization of the California Water Project or the steps being taken to implement it. Instead, we were hoping to be able to use in our proposed study the valuable experiences gained and "ground truth" data

acquired by those who had been working for many years on the California Water Project. We realized that it would be prohibitively costly and time consuming for us to attempt to acquire this same kind of "input" independently. However it was our belief, as expressed in our proposal, that this situation enhanced the usefulness of the state of California as a "calibration" project, so that our research findings could be applied, by extrapolation, to other parts of the world that were less developed than California, yet highly analogous to it in terms of characteristics of the total resource complex. By the time these discussions had been concluded, an amicable relationship with the Administrative Branch had been developed and this fact was made known to the appropriate NASA authorities at the time when final consideration was being given to our proposal.

The emphasis that has just been given to matters of "protocol" is a highly purposeful one. For it seems quite possible that the future success for the entire NASA-sponsored Earth Resources Survey Program, especially as it approaches a semi-operational phase, could depend in very large measure upon the extent to which attention is given to such matters by the various NASA-funded investigators. Resource managers are subjected to ever-increasing amounts of criticism by those who seek to command attention by being so bold as to "second-guess" the wisdom of certain resource management decisions. These critics range all the way from a certain group of discourteous antagonists known as "eco-freaks" to individual politicians who are almost desperately in search of issues which will constitute suitable planks in their platforms. In the presence of such potential criticism, many resource managers are becoming

increasingly sensitive about the kinds of resource surveys that should be permitted. Criticism, or even the prospect of it, can beget counter-criticism, and the age-old maxim that "the best defense is a vigorous offense" can prompt some resource managers to seek to discredit at the outset any individual or group who seemingly is about to delve into their affairs. To ignore this fact in future studies conducted under the NASA Earth Resources Survey Program might be to ensure at the outset the ultimate failure of such studies -- and the more closely these studies become of operational significance, the greater the likelihood that attempts will be made to discredit them. So important is this development, in the view of the present writer, that it will be referred to again in a concluding chapter of this report, but with reference there primarily to its international implications.

## 1.2 TYPES OF INTEGRATION BEING SOUGHT IN THE STUDY

We are making a sizeable effort to achieve "integration" in our study from three standpoints, data acquisition, data analysis and data use as indicated in the three paragraphs which follow.

From the data acquisition standpoint this study seeks to integrate: (1) data acquired from sensors operating in several wavelength bands (the Multispectral or Multiband concept); (2) data acquired from sensors operating at several different times (the Temporal or Multidate concept); (3) data acquired from two or more stations in the same flight path (the Parallax or Multistation concept); (4) data acquired using both like- and cross-polarization sensors (the Multipolarization concept); (5) data acquired from two or more nearly identical images (the "improved signal-

to-noise" or Multi-image Correlation concept); and (6) data acquired from space, air and ground (the Multi-stage concept).

From the data analysis standpoint this study seeks to integrate:

(1) analyses contributed by analysts from several disciplines (the Multi-disciplinary concept); (2) analyses made possible through the making of various optical and electronic image enhancements (the Multi-enhancement concept); and (3) analyses made possible through proper interaction between humans and machines (the "Human" vs. "Automatic" or Multiple Data Processing concept).

From the information use standpoint this study seeks to integrate:

(1) information about all components of the total resource "complex" and the inter-relations of these components (the Multi-resource concept); (2) information needed in producing several kinds of earth resource products from the same piece of property (the Multi-use concept); (3) information needed by several types of earth resource managers and consumers (the Multi-user concept); (4) information displayed in various formats (thematic maps, 3-D models, annotated photo mosaics, tables, graphs, etc.) to best satisfy the various multi-use and multi-user requirements and preferences (the Multi- display concept); and (5) information about inter-relations among earth resource components and the uses of these components in one geographic area vs. another (the Multi-association concept).

While this "multi" concept could be still further enlarged upon, perhaps it already has been overdone in the preceding paragraphs. Nevertheless, at the very heart of our integrated study is the central theme implied above and expressed as follows: The providing of useful information about earth resources through the use of remote sensing techniques

is, at best, a difficult task. In fact it becomes an almost futile task if only one image of the area of interest is given in the completely unenhanced form, to one analyst, and he uses only one approach in attempting to extract information from it that might be of use to only one of the host of potential beneficiaries of such information. In contrast with this limited approach, each of the "multi" concepts just expressed may add a small amount to his ability to improve the usefulness of resource information that he is attempting to provide. Furthermore, the overall usefulness of the final product may be improved far more than might be suggested merely by summing up the improvements made possible through individually employing these various "multi" concepts, as appropriate. Hence, at some point in the process a threshold is crossed, to the left of which the information acquired by remote sensing is virtually worthless and to the right of which it becomes progressively more useful, even to the point of becoming the most useful combination of tools and techniques available to those interested in achieving the wisest possible management of this globe's critically limited complex of earth resources.

Figure 1.1 shows the locations of study areas for certain of the participants in this 6 campus project. A seventh campus (San Diego) also is shown because of the probability that participation by scientists from that campus also may become a reality in the near future. In the chapters which follow the findings of participants from these various campuses during the present reporting period (May-December, 1971) are reported upon in detail.

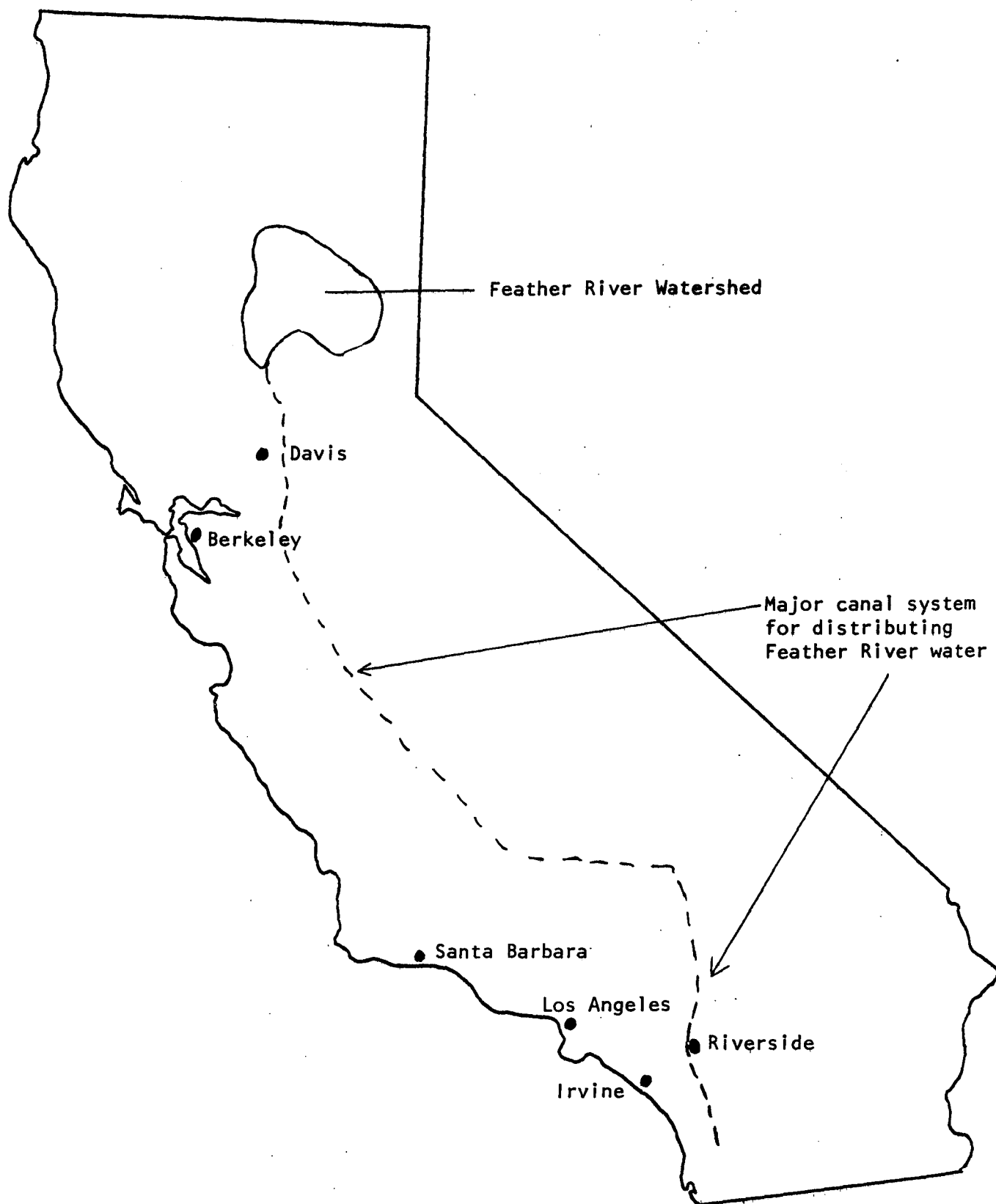


Figure 1.1. Location of participating campuses that are involved in the Integrated Study and their relation to the California Water Project.



There are two important additional respects in which we believe this to be a well-integrated study: (1) The scientists who are participating in our study on 6 campuses of the University of California are very effective in keeping each other well-informed about their various activities, particularly in those aspects of the integrated study which might otherwise result in needless duplication. Some evidence that this high level of integration is real rather than fancied will be found in the frequent cross-referencing, in the various chapters which follow, to related work by project participants being done on other campuses. (2) Corollary to this is the effort being made in our study to maintain liaison with other NASA-funded scientists whose interests may be closely related to ours. Only one such example will be given here, but others appear in the chapters which follow.

The National Aeronautics and Space Administration has a very active Advanced Concepts and Missions Division at Moffett Field, California. Early in our own NASA-funded studies we learned of a study being conducted by that group under the leadership of Dr. Jerry M. Deerwester, Chief of the Space Utilization and Technology Branch, entitled, "Data Acquisition Systems for Operational Earth Observation Missions". Several meetings between that group and ours have established the fact that much is being gained by integrating certain aspects of our efforts with theirs. For example, Dr. Deerwester's group seeks to identify, under the above-mentioned study, the data acquisition system that is expected to be available in the 1980 time period as part of operational Earth observations missions. The data acquisition system, as it is regarded by that group, includes the sensor platform (spacecraft or aircraft), the sensors

themselves and the communication system. The acquisition system, together with the data handling system is regarded as comprising the total observation system.

In addition to the projections of future operational capabilities, Deerwester's study has two other objectives. The first is to identify the technology efforts needed to bring the presumed capabilities for the most promising options to fruition. Second, in the words of his November 8, 1971 report, "it is hoped that the study of future operational capabilities together with the actual performance of the intervening development programs (ERTS, Skylab, and the Earth Resources Aircraft Program) can act as a catalyst to the iterative process that will eventually lead to the proper balance between capabilities and user requirements".

Future capabilities and support requirements are projected in Deerwester's study for the following sensors:

1. Film camera sensors, including those which will employ on-board processing.
2. Return beam vidicon; of the type to be aboard ERTS A and B.
3. Multispectral scanner; of the type to be aboard ERTS A; five bands in the visual through the near IR.
4. Infrared scanner; one band in the thermal IR; also a sixth band of a multispectral scanner of the type to be aboard ERTS B.
5. Infrared radiometer.
6. Microwave scanner.
7. Microwave radiometer.
8. Coherent side-looking radar.
9. Scatterometer.

Results of the study are presented for the most part in parametric form in Deerwester's latest report, as cited above. For each sensor class, charts are shown that depict swath width and spatial resolution (and, as appropriate, temperature resolution) as functions of the sensor design parameters; projected technology boundaries are also shown. Companion charts of data acquisition rates and spacecraft weights are included.

In addition to these sensor-related results, parametric analyses were also conducted with reference to Spacecraft Orbit, Selecting Cloud Cover Effects, Aircraft Coverage Capabilities and Communication Systems. The latter deals with both real time data transmission and the contribution of on-board data storage.

The many ways in which the study by Deerwester's group overlaps ours should be immediately apparent from the above listing yet, through our maintenance of adequate liaison with that group, duplication is minimized and integration of the type that is so essential to our own study is achieved in a highly beneficial way for both their study and ours.

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## Chapter 2

### DEFINITION OF EARTH RESOURCE POLICY AND MANAGEMENT PROBLEMS IN CALIFORNIA

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Contributors: William Gotcher, Ida Hoos, Ralph Lewis, Richard O. Mason

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#### 2.1 INTRODUCTION

In the proposal for the Integrated Study, the Social Sciences Group emphasized the need to understand the "beneficiaries" of the ERTS technology, their relationship to the ERTS information, and specifically, the decisions which could be influenced by this information. (A "beneficiary" was defined as someone whose interests might be served by the system.)

Up to the present time, most of the work done on the project has been in the nature of orientation, that is, an exploration of the most useful role for the Social Sciences Group in the larger context of the Integrated Study; search for fruitful areas of research; and structuring of questions relevant to NASA's objectives in the ERTS program. As can be seen in the documents appended to this report, there have been three main, and a number of subsidiary and supporting, lines of endeavor: (a) a clearer definition of questions that needed clarification and definition before meaningful answers could be sought; (b) development of a taxonomy of beneficiaries of ERTS data, as, for example, agency heads; and (c) preliminary modeling of the Feather River Project.

Our research indicates that ERTS and its data will be looked at from many different perspectives. Although the stated objective of ERTS is an inventory of earth resources, the spinoff has vastly greater significance. The ERTS program, viewed in a narrow framework as a source of information for decision makers, can be construed in a larger sense as a vehicle for total surveillance of the earth and all human activity on it. ERTS can yield information that bears not only on immediate technical, economic, and social concerns and arrangements but also on decisions that may alter the bio-mass in irreversible ways. Despite high-flown rhetoric about the need for global resource management, there has been a remarkable dearth of bona fide, open-end research. No other study known to us has directed its energies to ascertaining the possible impacts of remote sensing on the human population. Instead, mission-directed projects contracted out to "think tanks" have yielded limited views, generally in substantiation of positions already taken. By contrast, through recognition and study of the socially relevant implications of ERTS technology, the Social Sciences Group of the Integrated Study expects to provide NASA with a unique capability which will complement its accomplishments in the technical aspects of remote sensing.

Our work has convinced us that the lives and business of many persons will be affected directly by ERTS technology. These individuals will perceive the ERTS system in radically different ways, some negative, some positive. Some will see it as an economic

benefit, some as a threat to privacy, some as an implement for man's exploitation of the environment, some as a waste of money, and so on. We are convinced that the federal agency responsible for the collection and dissemination of ERTS data can neither expect to find nor create a unanimity of citizen opinion. NASA, in order to be prepared to be responsive to these conflicting perspectives, should, it seems to us, take advantage of the experimental situation provided by its ERTS program by fostering the research that will lead to fuller understanding. This foresighted approach is consistent with the current interest in Congress in technology assessment. In broader terms, our approach and intent might be construed as pre-assessment, in that our Group studies the consequences and implications for the long run.

To date a number of documents have been written by the Social Sciences Group. In this report we have included some of these to illustrate our approach in detail. The others are available on request.

## 2.2 SYSTEMS ANALYSIS--STATE-OF-THE-ART ASSESSED

Since the social science orientation of the Integrated Project has consisted of a systems approach to the ERTS effort, a statement at the beginning will help clarify what is meant by this concept in our research. It should be pointed out that each new technological development of the type represented by the ERTS effort in itself requires a redesign of the systems approach, i.e., of the socioeconomic

analysis of the technology. To date, we have not been able to rely satisfactorily on previous methodology developed for earlier technologies. A partial reason for this need to redesign the "inquiring system"<sup>\*</sup> is that with each attempt to apply the systems approach there has been the concomitant learning on the part of the systems analyst. Thus, some of the activity of the Social Sciences Group has consisted of an attempt so to design their own research within the Integrated Study as to have maximum effectiveness, from the socioeconomic point of view, for what the ERTS program will eventually accomplish.

A brief review of the history of the development of the systems approach will provide perspective for these remarks and indicate how ERTS research will help advance the state-of-the-art of systems analysis. Developed and applied so successfully by NASA in the management of its affairs, the techniques must now undergo considerable mutation in order to be usable when the interface with society at large becomes crucial.

During World War II, operations research teams utilized the systems approach as essentially a series of analyses of specific military problems, in which the systems analyst was not required to pay much attention to the system's goals because these were often so well defined by the military missions. The period after World War II

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<sup>\*</sup>See C. W. Churchman, The Design of Inquiring Systems, New York: Basic Books, December 1971.

saw an enormous development in our capability of modeling various kinds of systems. Applications in the industrial milieu clearly indicated that the systems analyst had to go far beyond his forebears in World War II operations research. It was essential in this period to pay considerable attention to the determination of specific goals since managers of firms were frequently unsure about which goals should be achieved. In the absence of explicit direction, the systems analyst could have pursued wrong objectives in a very precise manner.

In this regard the systems analyst soon learned that it was not enough simply to ask the manager what decisions he had to make in order to assist him in making better decisions. This tactic had led to faulty pathways of analysis, since the decisions made by the manager often left out some of the most crucial opportunities that were at his disposal. Accepted procedures at that time had a backward thrust that virtually stymied exploration of new paths and possibilities. It was from this experience that systems analysts during the 1940's began to realize that it was their responsibility to make as broad a perspective of the system as possible. However, the emphasis on models in the 1950's constrained the systems analysts primarily to economic objectives because these were most amenable to representation by linear programming, nonlinear programming, dynamic programming, and the other technical tools rapidly gaining in use and sophistication.



The 1960's marked the beginning of an era when social concerns and issues became more central to the "systems approach". Consequently, it became even more obvious to the systems analyst that the systems approach of the 1950's no longer suited his own purposes since its emphasis on economic values often left out some of the most critical public aspects of the problem. There were numerous attempts during the 1960's to cope with such problems as poverty, pollution, mass transportation, and the implications of new technology, and these could not be adequately represented within economic scales at least as they were applied during the 1950's. In at least the most advanced systems approach of the 1960's there was a modification of the models in terms of some of the broader social aspects. Often these modifications were introduced as constraints on the "objective function" of the models, sometimes as simulation or gaming.

### 2.3 SYSTEMS ANALYSIS FOR THE 70's--NEW PERSPECTIVES FOR ERTS

For the 1970's, the Social Sciences Group of the Integrated Study has become convinced that the most advanced systems approach will have to involve still other considerations, not taken into account in the 1960's. Some of these were already noted in commentaries and criticisms of the systems analysis efforts of the 1960's.\* For example, it became clear that a very important value that had to be

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\*Extensive research on systems analysis has been conducted by Ida R. Hoos, a member of the Social Sciences Group. Her work has been reported in papers in the earlier Working Paper Series. Her book, Systems Analysis in Public Policy, is in press (University of California Press) and will appear in May, 1972. See Addendum A.

taken into account was the participation of individuals who were involved in the system. Participation could be viewed as an effort to encompass within the "objective" measure of the system the interests and opinions of as many individuals who are concerned about the system as possible. But there are deeper aspects of participation which were largely neglected during the 1960's by systems analysts. These included such matters as invasion of the privacy of individuals who have had nothing whatsoever to do with the design of the system; the creation of new policies without individuals in the community being aware of them, and so on.

The 1960's saw an increased interest in what were called "adaptive systems". This interest arose out of the fact that many systems scientists realized that their own efforts might easily be based on either the wrong data, or, more seriously and more frequently, on the wrong conception of the problem. Consequently, they recognized the need to design the system approach in such a way that it would be possible to correct for errors in the analysis in the event that further experience indicated that either of the two kinds of errors had indeed occurred.

But we have come to realize that the 1970's face a much deeper concern that cannot be handled simply by the creation of adaptive methodologies. Associated with every systems approach to a technology there has been a strong underlying assumption as to the nature of the reality of the system. Often this assumption is taken to be rather obvious by the systems analyst. To use ERTS as an example, it may be assumed that the basic reality is the state of the various earth

resources at any moment of time when ERTS imagery is obtained; therefore it may be assumed that the "business" of the ERTS system is essentially to obtain information about the real resources in as reliable a form as possible for those who "need" it in society. This is a more or less obvious way to look at the ERTS system, but it should be pointed out that it is based on one very strong and questionable assumption. The "reality" with which the ERTS system is concerned is only secondarily described in terms of the resources of which ERTS is taking images. The primary reality of the ERTS system is the ways in which the imagery will be used to satisfy societal needs; more specifically, the reality of the ERTS system is the societal needs themselves. Therefore, one must include these realities into the basic assumptions to be used by the systems analyst. But why not use the lessons gained from the 1950's and the 1960's and simply say that the "needs" of society are "really" those that can be identified with economic needs and with the broader societal needs of participation, privacy and the like?

#### 2.3.1 Various Possible Approaches to the Business of ERTS

To see why this question has no simple answer we can return to ERTS technology itself and note that ERTS and auxiliary aircraft are not merely taking images of earth resources. To take such images is of course the intent of the designers of the ERTS program, but ERTS technology will be taking images of many aspects of nature which cannot be regarded as resources. For example, there will be images

of what people are doing with their land, how people are camping in recreational areas, and eventually with more refined imagery, images of various kinds of activities within urban areas. Hence, it would be more accurate to say that ERTS technology is in the business of taking imagery of the earth's surface, and not merely of the resources on the earth. It will, in fact, be the first time in human history that man has been capable of receiving on a regular and rapid schedule pictures of how events are taking place and changing around the earth.

One realizes the openness of the ERTS system when one also sees that the "business" of the ERTS technology is also wide open. It may indeed be in the business of providing resource information to those best able to make use of changes in earth's resources for the benefit of the whole of society. But it will also be in the business of supplying the information to those who wish to police the world in a certain manner; to those who wish to redesign urban and agricultural communities; and to those who wish to control society and its resources in a certain manner. The important point then is that the analysis of the ERTS system in "socioeconomic terms" depends on which assumptions one makes about the total system within which ERTS technology operates.

Finally, one other aspect of the systems approach of the 1970's needs to be emphasized. This became apparent in the seminar on research management associated with our earlier work under NASA

sponsorship. The principle underlying this facet of the systems approach is as follows: a systems approach should include an explicit study of the inquiring system itself, i.e., of the research team and its appropriate activities. In most systems approaches to date, the approach is more or less taken for granted, based on what Thomas S. Kuhn\* calls the "paradigm" of the particular discipline of science, in this case the paradigm of model-building operations researchers. But in order that a model-builder operate successfully with respect to a system he is studying, he himself has to have an image of reality; usually he assumes that reality is essentially rational and observable. From the rationality of nature he is able to make certain general inferences which appear as the equations of his model, and from the observability of nature he is able to "fill in" the details of his model. Once we realize that the inquiring system itself requires an image of nature and therefore of the system, we can begin to appreciate the "bias" of the inquiring system: it is forced to represent the system in a way that is adaptable to its own image of nature. Thus the inquiring system of the 1960's, using the systems approach, was forced to regard society as potentially rational and observable. Its aim was to introduce rationality into the societal design according to its own concept of the rational. The point is made most strongly in the case of cost/benefit analysis, where it is assumed that by observing certain

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\*The Structure of Scientific Revolutions, Chicago: University of Chicago Press, 1962, 172 pp.

aspects of society one can infer, or make a best estimate of, the optimal policy that society should follow, e.g., the optimal policy for the utilization of ERTS information.

How does the realization that the nature of the inquiring system itself must be included in the systems approach lead to practical results for an agency like the National Aeronautics and Space Administration? This question amounts to asking how a team stationed at several campuses of the University of California can most effectively aid NASA and other federal and state government agencies in their policy making, with respect to the utilization of ERTS information. Our conclusion has been that the most effective way in which a university-based team with a wide interdisciplinary set of resources can aid policy makers at both federal and state levels is to provide them with as many perspectives as possible concerning the ERTS system, i.e., the "business" that the ERTS technology is "really" in. This is what we have set out to do in the first two years of the ERTS project.

In order to describe these imageries it is necessary to introduce a common structure. We have assumed in each imagery that the system can be described in the following terms: there exists a set of individuals whom the system ought legitimately and ethically to serve. These are called the clients or "beneficiaries" of the system. Measure of performance of the system is how well it does indeed serve the appropriate client. In many instances the ultimate client of the system has a surrogate, e.g., governmental agency heads and their

staffs, who according to the imagery act in the best interests of the ultimate client. Second, there is a body of persons called the decision maker who have the legal and ethical authority to change the system in a certain manner. This they do by changing certain aspects of the components of the system. These changes then lead (e.g., as in the case of a mathematical program) to successful changes in the measure of performance of the total system. The decision makers operate within an environment which also affects the measure of performance of the system but which is outside of the control of the decision makers. Third, in the systems approach as we mentioned above, there is always the inquiring system, i.e., the designers or planners of the system, who expect that their plans will have an effective influence on the decision makers in the service of the correct client. It should be noted that in many instances in the systems approach it is not possible to generate a true measure of performance of the system. Instead we often have to resort to surrogate measures as in cost/benefit analysis or, in the private sector, an accountant's measure of net profit, neither one of which truly represents the real values of the client, but which are taken to come close enough to the client's real interests.\*

The different perspectives or images that we have tried to develop are as follows: (1) that the business of the ERTS technology is primarily earth resources and that every effort must be made to  

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For further details, see The Design of Inquiring Systems, noted above.

prevent ERTS technology from being used for other business besides this one. According to this perspective, the ultimate clients of the system are the legitimate ultimate users of earth resources: the farmer, the urban dweller, the individuals using the land for recreation, and so on. The surrogate clients are the heads of agencies and their staff who presumably receive the information and make decisions that will be beneficial for the ultimate client. These agency heads are in effect the decision makers along with the legislative bodies and others who have something to say about how land is used (e.g., by the private sector). During the first year an in-depth study was made of the needs of agency heads for ERTS information. The results of this study and other relevant information are contained in Section 2.3.2. The measure of performance is the net social benefit of the ERTS program as measured, say, along economic scales supplemented by various kinds of policy constraints.

On the basis of the preliminary findings and reflecting the suggestion which emerged from user meetings (see pages 2-19 to 2-28) that some state of California agency be designated as a "demonstration project" with respect to utilization of data from remote sensing technology, a case study of the Department of Agriculture has been designed by Dr. Ida R. Hoos. Initial focus will be on the organization structure, the relationships among divisions and between the state Department of Agriculture and other levels of government. Within this framework, there is to be a study of the traditional sources and methods of information-gathering, the channels through which data flows, and the patterns by which decisions



are made operational. A crucial element here is the identification of decision-makers, who will be canvassed for the purpose of ascertaining their conceptions of their tasks and their views of how they might utilize ERTS data and how ERTS data might affect them. Of interest in this respect is a consideration of the ways in which the availability and utilization of ERTS data might alter established practices and ultimately affect organizational structure and decision-making patterns. It is expected that during the course of the case study, various views of ERTS data will emerge and that these will eventually have considerable impact on programs and policy. Consequently, one portion of the study will focus on a broad spectrum of possible "receptors" of ERTS data -- the agri-business community at large; growers, as individuals and as members of associations (such as the California Cling Peach Association, the California Wine Institute, the California Canning Pear Association, etc.); and legislative regulatory bodies. It is anticipated that the findings of this case study will contribute directly to a better understanding of the potential role of ERTS in carrying forward the objectives of one of California's most important agencies.

The "business as usual" image of ERTS technology is one that suggests that a successful ERTS technology will require the design of a federally based resource information agency. Two models for such an agency are under consideration: the Bureau of the Census and NOAA. This work, under development by J. William Gotcher, is summarized in Addendum B.

A broader approach to the "business as usual" image of the ERTS system is to look at it from the international point of view as was

originally intended at the start of the integrated study. Some of the basic issues underlying such a design of an ERTS system from an international point of view are being studied at the Irvine Campus in the Policy and Planning Research Organization. A copy of their proposed research (which began in October, 1971) is included as Addendum C.

The second image of the ERTS system is a system which is much broader than ERTS resources themselves and their economic benefits and costs. As indicated in the Progress Report of May 1, 1971, we have in the past paid considerable attention to the one alternative strategy for a broader look at the ERTS system, namely the macro-model. At that time we considered the possibility of working with the operations research team at the Boise-Cascade Company, since that team had developed a large-scale linear program utilizing the decomposition algorithm. In the spring of 1971, the operations research team at Boise-Cascade had a change in personnel; this change made further cooperation with Boise-Cascade unfruitful. So further thought of developing such cooperation was abandoned.

Consequently, we have been devoting our energy to a second approach to a large-scale view of the ERTS system, namely a more qualitative comparison of perspectives of the system. At Berkeley and Los Angeles we have been developing a new technique for systems

analysis over the past six years, which we call the "dialectical" approach. One example of the dialectical approach appears in the paper called "Beyond Benefits and Costs: A Study on Methods for Evaluating a NASA-ERTS Program" by Richard O. Mason. A summary of the paper is included in this report. See Addendum D.

The basis for the dialectical approach is also discussed in many of the papers by C. W. Churchman in the Internal Working Paper series, a list of which is attached. See Addendum E. One of these papers, forthcoming in a volume published by the American Federation of Information Processing Societies, goes into further detail on the development of the systems approach and its relationship to information systems such as ERTS. A copy of this paper is included as Addendum F.

One perspective of the ERTS system with respect to the decision makers and clients assumes that the entire public, which cannot be adequately represented by a state or federal agency, should be the decision making body. This viewpoint has been discussed in a paper by Ralph Lewis at the University of California at Los Angeles. Entitled "Decisions in a Technologically Based Culture," it outlines a thesis to the effect that the public elects representatives to hire experts to recommend policies which are decided by the representatives; he poses against it the antithesis that the best way to formulate good social decisions is to get everyone involved because this makes use of human intelligence in social decision problem solving. Lewis

then attempts a synthesis of these two viewpoints by use of some of the recent writings of the social psychologists and psychologists on human values and the way in which man can learn about his values. Lewis's paper is a basis of an empirical study of personal attitudes of the public with respect to earth resources. Feasibility of this study has been tested in another area and the questionnaire forms are now being constructed. A description of the proposed survey is included in Addendum G.

So far the imagery of the "business that ERTS is in" has depended entirely on the concept that ERTS is in the business of serving either a sector of humanity or else the whole of humanity. We would not be adequately representing the spectrum of perspectives of the ERTS system if we did not also consider that humanity may not be the sole client but only one of the clients of the earth resource system. This perspective, although not new, has been neglected in western writings, especially in the 19th and 20th centuries. Richard O. Mason has prepared a paper in which he compares the thesis of "progress as the cooperation of man with man in the conquest of nature" against the antithesis of nature for nature's sake. This again is represented in the form of a debate between "Bud" and "Adam," Bud representing the Buddhist tradition of nature for nature's sake and Adam, the Adam Smith tradition of nature in the service of man. See Addendum H.

Research on the nature of the inquiring system itself is taking place. The focus here is on the Social Sciences Group and the total

Integrated Study as an important example of the dynamics of the interdisciplinary approach, which has been more described in the literature than practiced in reality. The University of California experience has direct applicability not only to NASA's immediate interest in discovering ways in which to make ERTS relevant but in a larger sense to the effects of the introduction of technological sophistication at home and abroad. Dr. Hoos is preparing a research report on the Social Sciences Group's ten-year experience; the in-depth analysis of the decade of work accomplished by the members and the Seminar under the direction of Professor C. West Churchman covers such vital topics as science policy making in a democracy; information as concept and commodity; the design of inquiring systems; information technology and the invasion of privacy; exploration into new dimensions of systems analysis, ethics of experimentation in research; political and social perturbations caused by the introduction of new technologies; and the control and direction of technology. A detailed outline of the study by Dr. Hoos is included in Addendum I.

This research report should be of special significance as background for the present integrated approach to ERTS. Indeed, a successful integrated study may well be a model for ERTS' inevitable world role, for it is abundantly clear that, just as in the local milieu, there are many possible views of, reactions to, uses for, and users of the new technology, so in global terms, these exist and

are enormously expanded.\*

Another facet of the Social Sciences Group's research has concentrated on the way in which the present Group can best work with the Integrated Study. In this regard, it should again be emphasized that at present the rest of the Integrated Study has as its primary focus the Feather River and Los Angeles Basin, together with certain coastal areas. The implications of what the Social Sciences Group has been doing on a much broader plane are clear as they are applied to the specific Feather River Project. The different perspectives of the business that ERTS is engaged in have been clarified through the attempt to apply each one specifically to the Feather River Project.

#### 2.3.2 Statement of Preliminary Activities in Ascertaining Users' Needs

The primary users of the information that will be derived from ERTS presumably will be those persons who make policy decisions about earth resources. Hence the Social Sciences Group set itself the tasks of identifying such persons and of determining what types of decisions are made by them, what kinds of information might be useful to them, and how data gathered by ERTS and supporting aircraft might be translated and transmitted to them so as to insure a meaningful and useful product.

With government agency heads and administrators identified as

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\*The problems generated by technology transfer have received official recognition and high priority by the Agency for International Development, which recently (November 25, 1971) allocated \$900,000 to MIT for a 5-year interdisciplinary program intended to ascertain the effects of technology on developing countries.

the key persons, i.e., as potential ultimate recipients of the data, members of the Social Sciences Group tried (1) to learn their data needs as they perceived them; (2) to determine what such information might be worth to them; (3) to ascertain their views on the utilization of ERTS data in performing their official tasks in a more expeditious, efficient, and beneficial manner.

Interviews with a considerable number of managers disclosed a substantial lack of knowledge about earth resources satellite technology and its potential applications. It was evident that an educational process had to be set in motion and that it should be constructed on a feedback principle so that managers, once enlightened, could give back to ERTS planners the practical insights and guidelines sought.

On the basis of a survey of user interest achieved through distribution and analysis of about 1000 questionnaires, the general "climate" for ERTS data was sampled, and a 5-day seminar conducted at Lake Arrowhead, California. Attended by representatives of federal and state agencies and of private corporations, the sessions were devoted to orientation, exposure to the new technology, and discussion. Members of the University of California Integrated Study led sessions on the following topics:

- I. Forest Uses and Management
- II. Water Uses and Management
- III. Agriculture and Rural Uses

#### IV. Urban, Coastal and Community Planning

#### V. General Land Use Topics

During the question-and-answer periods which followed each presentation, discussion centered on the specific data needs of administrators and the potential of the available ERTS technology for meeting them. Summaries of proposed uses appear in Tables 2.1 to 2.4.

The interest thus generated served as a valuable guide to possible users as well as to areas which needed further elucidation and interpretation. The Arrowhead Conference was followed by a number of interviews with likely special user groups, as, for example, those in the California Resources Agency, the California Department of Agriculture, the U.S. Geological Survey, and the U.S. Forest Service. Subsequent meetings at NASA-Ames explored certain aspects of the ERTS program in greater detail in plenary and workshop sessions addressed to specific information needs. In cooperation with the Advanced Concepts and Missions Division at Ames, the Integrated Study members met with representatives of the potential user community. The range of topics was from the technical to the practical. Participants included the Ames people, Dr. Colwell and his various technical specialists, and members of the Social Sciences Group and representatives from the above named federal and state agencies and from private industry.

One set of considerations focused on the resolution of the imagery: would it yield usable information on land forms, vegetation, geology, soils, hydrology and land use? How frequently did managers need to have reports on certain conditions? Would a common answer be forth-



PROPOSED USES FOR ERTS DATA

IMAGE/USES TYPE	FIRE CONTROL	MULTIPLE USE	SOILS	TRANSPORTATION	ALASKA
Resolution 200' - 300' 18-day repetition	-Fuel condition -Measure of vegetation condition (dry, green)	-Gross land use -Stratification of resources -Change detection	-Soil patterns (associations) -Drainage conditions -Salinity	-Networks -Model inputs	-Fire -- long-term -Unique features -Tundra recovery
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General: (Use in Public Education Presentation) and Damage Assessment					
Resolution 200' - 300' near real time	-Improved assessment of fuel condition -Fuel moisture conditions by secondary phenomena (i.e., veg. soil tone) -Prevention planning more effective in real time	-Damage assessment: Drought Hurricanes Earthquakes Floods -Burned or damaged area rehabilitation (slides, disaster, blow-down)	-Soil temp. (ERTS-B) -Seeding -- exp. cotton -Moisture change -Soil condition change	-Inland water and road conditions -May serve as a change indicator; following logging operations -Sedimentation -Transportation routes for air cushion vehicles	
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Great Improvement in Damage Assessment					
Higher resolution -15' (man-ned) -150'-200' (unmanned) near real time	-Dynamic measurement of heat sources (and secondary effects)	-Develop dynamic land use planning on a national scale	-Small soil unit inventory	-Traffic analysis -Logging operations -Recreation	

Table 2.1. Summary of Seminar I -- Forest Uses and Management, December 6 and 7, 1970.

IMAGE/USES TYPE	SNOW	WATER	CLOUDS	ICE	VEGETATION	SOIL	SEDIMENT AND POLLUTANTS
200'-300' 18-day repetition rate	-Areal extent	-Areal extent: depth (possibly) surface areas	-Areal extent	-Areal extent: ratio of ice to open water	-Areal extent: by type and water require- ment. Changes in coastal and marsh vegetation as an indicator of water quality	-Areal extent: surface soil pond- ing during floods	-Areal extent: oil and water spills (synop- tic reporting) parameters, dispersion, movement life- time
200'-300' near real time	-Spring thaw of ice -Flow movements	-Water quality -Water drainage -Thermal grada- tion can be used to check thermal dis- charge			-Sequential ob- servation where salinity is a problem		-Possible detec- tion of Eutro- phication in large water bodies
Higher resolu- tion -15' (manned) -150'-200' (unmanned) near real time	-Snow cover depth and water con- tent -Snow cover data by active and passive microwave	-Sedimentation plumes more accurately delineated -Regulatory use for thermal pollution				-Acquifer detection and defini- tion by IR (4-6AM) Radar, and passive microwave	-Eutrophication monitoring

Table 2.2. Summary of Seminar II -- Water Uses and Management, December 7 and 8, 1970.

IMAGE/USES TYPE	LAND USE	CROP TYPE	SOIL - LAND POTENTIAL	DAMAGING AGENTS	YIELD	LIVESTOCK	LAND TREATMENT
Resolution 200'-300' 18-day repetition rate	-Irrigated vs. non- irrigated -Agricul- tural vs. non-agri- cultural	Major differen- ces: -Agricultural crops -Grassland -Assessing of fertiliza- tion	-Salinity -Major soil associations -Gross topo- graphical changes -Geomorphology -Shallow water table	Detection of: -Watershed damage -Drought -Logging -Water -Wind ero- sion -Insects -Disease	Stratifi- cation of low yield areas	-Indirect evidence of animal presence, i.e., which side of fence	-Cropping -Terracing -Water reservoir -Windbreaks -Stock water ponds -Reforestation
Resolution 200'-300' near real time	-Irrigated vs. non- irrigated	-Increased ef- fectiveness of crop identification	-Detection of surface water	-Detection of frost damage		-Detection of rein- deer and caribou	-Brush conversion -Fertilizer effects
Higher resolution -15' (man- ned) -150'-200' (unmanned) near real time	-Sprinkler vs. row irrigation	Crop inven- tories	-Sprinkler vs. Increased flood irriga- tion -Topography (slope class) and -Aquifers	Increased effectiveness for damage detection and monitoring		-Indirect detection and moni- toring -Evaluation of effects of animal use	

Table 2.3. Summary of Seminar III -- Agriculture and Rural Uses, December 8 and 9, 1970.

IMAGE TYPE	USES	NATURAL FEATURES	MAN-MADE FEATURES	SOCIAL ENVIRONMENT	REGULATION USES	COASTAL & MARINE
Resolution 200'-300' 18-day repetition rate		-Hydrology -Vegetation -Geology -Topography -Soil -Hazard	-Urban settle- ment -Land use -Transportation systems	-Scenic features -Air pollution -Water pollution -Thermal pollu- tion		-Currents -Water color -Coastline ther- mal and pollu- tion plumes
Resolution 200'-300' near real time		-Location change detection	-Location change detection	-Check land use changes -- boundaries, territories	-Zoning, inter- regional comparisons	
Higher reso- lution -15' (manned) -150'-200' (unmanned) near real time			-Check land use changes -- boundaries	-Possibility of blight detec- tion		

Table 2.4 Summary of Seminar IV -- Urban, Community and Coastal Uses, December 9 and 10, 1970.

coming from ERTS for the vast array of rather specialized data needs of the various interested agencies? Would agencies want original data? digitalized data? photographs? A second set of considerations resulted from the fact that agency representatives were primarily concerned with the effects of the new information sources on their operations. The consensus was that even if the most technologically advanced methods, geared directly to their needs, were to be made available, little would be gained unless the information reached the right person in the agency; that person could not be pinpointed by mere reference to the table of organization. Participants were interested, to a somewhat lesser degree, in costs of the data. The thought was expressed by several of them that if the ERTS data were free, their agency might be willing to pay for analysis of it. Otherwise, because of the existence of other data sources, and because ERTS data might entail new bureaucratic procedures, the decision might be made in favor of using something other than ERTS.

A positive suggestion, rather well received, was that while ERTS was in its early and experimental stages some designated public agency, selected because it was likely to benefit directly from the kind of imagery ERTS could supply, should be utilized as a "demonstration" agency. If, for example, that agency were the California Department of Agriculture, then a joint effort, with direct involvement of technical specialists, social scientists, and government personnel, would ascertain needs, devise procedures, and, ultimately,

assess results. Better than the currently popular paper-and-pencil simulation, this would be a live case study, a worthwhile experiment from every viewpoint. There was general agreement that a well coordinated California project, with the six campus, multidisciplined participation of the University of California in cooperation with the various appropriate groups at NASA-Ames, working together with the interested public agency,\* could make a significant contribution to learning how best to utilize the remote sensing technology soon to become available.

Expansion of the potential user community to the international scene will, no doubt, occur as it becomes apparent that, in order to be successful, ERTS, like many other NASA programs, will soon become a multi-nation matter. Some of the important aspects relating to international cooperation in space have been analyzed by NASA's Professor Arnold W. Frutkin, Assistant Administrator for International Affairs. His studies\*\* have laid the groundwork for continued research as earth resources satellites add another dimension to space collaboration among nations. Much that is learned about the utilization of ERTS technology in the California project will be pertinent to the national and international purpose; already some members of

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\*Although represented at these meetings, California agencies were not yet officially committed to participating in an ERTS experiment. Several federal agencies, however, expressed the desire to pursue the matter further. The U.S. Forest Service and the U.S. Bureau of Land Management were especially interested.

\*\*Arnold W. Frutkin, International Cooperation in Space, Englewood Cliffs, New Jersey, Prentice-Hall, 1965.  
\_\_\_\_\_, "International Cooperation in Space," Science, Vol. 169, July 24, 1970, pp. 333-339.

the Integrated Study have been asked to assist other countries in formulating their plans to use remote sensing to implement their own development. Although still in the nascent stage, these efforts are exceedingly important and underscore the far-reaching importance of the Social Science Group's study of the user community in all its ramifications.

#### 2.4 FUTURE PROPOSED WORK

The Social Science Group of the University of California Integrated Study on Resources Satellites proposes during the coming year to concentrate on one specific aspect of the socioeconomic characteristics of the ERTS data, namely, on the development of a decision-making model for a government agency and specifically the Agricultural Department of the State of California. This agency has been selected because of the excellent relationships that have developed in the past between the Agricultural Department and the University of California, and most especially the relationships between the Secretary of Agriculture, Mr. Earl Coke, and the principal investigator of this project, Professor Robert Colwell.

Our proposal in effect takes us back to a proposal we made during the year 1970-71 when we were working closely with the operations research group at the Boise Cascade Company. This group proposed the development of a large scale linear programming model which would have a high degree of usefulness in decision-making with respect to the resources being observed by ERTS and other remote sensing vehicles. This part of the effort of the Social Science Group was postponed because the operations research group at Boise Cascade experienced certain internal difficulties that made further cooperation with the Social Science Group of the

University of California infeasible. With the limited funding available to us during the coming year we do not believe it possible to develop the large-scale model envisaged earlier, but we do see ways in which basic concepts of such a model can be applied and made useful in the utilization of ERTS and related data for a specific government agency.

The steps in the development of the model are as follows:

1. The identification of the decision-makers in the agency and the classification of the decisions they are now making; this would include their timing, the alternatives that must be scanned and the constraints under which the decisions must be made. It should be emphasized that this step really consists of two parts: first, an understanding of the decisions that are being made within the department, and second, an examination of decisions that might be made given the increased power of understanding created by ERTS technology and given the systems analysis itself.

2. In the development of the model the analyst must try to understand the considerations governing the decisions that are being made.

- A. Specifically, he needs to determine what set of goals is being sought, for whom, and why. This consideration will bring to bear much of the work that has been done during the past year on the whole problem of resource information as it specifically relates to satellite and related technologies. In the work in the last year, as reported in the progress report of December 1971, we tried to achieve an understanding of the different perspectives with respect to management information systems for resource management and the way the utilization of this information relates to various individuals in the nation. In this work



we have come to the conclusion that there are divergent perspectives of resource management which need to be considered in the development of decision-making models for government agencies. Hence, the determination of the goals that are being sought by the agency again takes place in two parts: (1) the way in which the agency now perceives the goals, and (2) the manner in which the goals are perceived by individuals outside the agency (the public, conservation groups, development entrepreneurs, etc.).

B. The second consideration governing the decision is the determination of how the decision relates to the goals as perceived by the decision-maker. This is really the basic logic of the model. For example, in the traditional linear programming model one tries to describe the goals in terms of a measure of performance which is then related to various activities, in this case various allocations of water for agricultural usage. The information then fits into the model by showing specifically how changes in such allocations affect the measure of performance.

C. This leads to the third consideration of the decision-making model, namely how the data should be used to improve the decisions, i.e., to improve the effectiveness of decisions relative to the perceived goals of the decision maker.

D. A fourth consideration of the decision-making model relates to interregional considerations. As Feather River water is allocated in various ways in the San Joaquin Valley, for example, these allocations will have their effects, say, in the Los Angeles region. Consequently, as we pointed out earlier in considering the large-scale linear programming

model, it is impossible to develop a decision-making model that relates specifically to one region only, since interregional considerations very definitely affect the overall measure of performance of the decisions that are being made.

E. Fifth, the decision-making model must also include the constraints on the decision-maker, i.e., the matters that cannot be decided by him but which nevertheless affect the quality of his decisions. For example, the total amount of water flowing through the system is governed in part by weather conditions outside the decision-maker's powers, political pressures, policies, laws, etc. All of these represent constraints on the decisions that are being made within the agency.

F. Finally, the decision-making model must also reflect conflicting viewpoints with respect to the goals. That is, the decision-maker in any agency must go beyond his own perception of what the goals are and appreciate and understand the alternative viewpoints with respect to the goals. He must do so because he must be responsive to political pressures of various kinds, from farmers, from conservation groups, from recreation entrepreneurs, and so on. We have pointed out in our work during the past year that the perspective with respect to resource goals, e.g., the utilization of the land for agricultural purposes, must even include responsiveness to the idea that decisions about land use and the use of earth resources are not exclusively the prerogative of man himself, and that there is a plausible position which argues that man must begin to consider himself as only one of the species and pay deference to the total natural development of the world and not just simply to the human-oriented world development.

The multiple perspectives, we believe, are extremely important and have not been included in decision-making models in the public domain, even though they obviously play an important practical role in the lives of decision-makers in government agencies. Typically, the model-builders try to relate decisions to goals without considering the fact that the decision-maker himself has to play a number of different roles with respect to the public he intends to serve. Consequently, it is inaccurate to say that data from the Earth Resources Satellite and related technology flows into a well organized decision-making system represented abstractly by a large scale linear program. The realities of public decision-making are such that the decision-maker is on one hand obliged to make a decision and on the other hand to be responsive to alternative views of social values that he himself does not hold but that are held by individuals and groups within the society he intends to serve. To ignore the need for this responsiveness on the part of the government decision-maker is simply to ignore a major aspect of his job.

Our proposed research method then consists of the following steps:

First, further development of the case study of the California Agriculture Department, its policies, its decision-making problems and its data needs with specific reference to ERTS and related technologies.

Second, the development of a decision-making model for the Department or for specific parts of the Department. Given the limited funding available to us, it will not be possible to generate a mathematical model which would accept ERTS and related data in a computer. The computer costs as well as the time demands for an adequate analysis would be far too great. In any event, it may not be appropriate at present

to develop such a specific model. We can accomplish at least the following: the specification of what needs to be done to create and implement such a model, as well as the costs of doing so and the probable advantages and disadvantages. We can also expect to generate a qualitative model which should point out the various features of the decision-making system, including the conflicting world views mentioned above, which can then act as a guide and aid in the practical decision-making with special emphasis on ERTS and related data.

It should be emphasized that we are by no means starting at baseline zero. Specifically, as has been earlier reported, we have already taken a number of steps with respect to the development of the model. The earlier work with Boise Cascade has led to the identification of some of the broad aspects of decision-making with respect to resources. The seminars which our group conducted during the first year of the study, both at Lake Arrowhead and at the NASA Ames Research Center, were followed by a number of interviews. This effort has already led to the basic information with respect to the development of a typology of decisions, i.e., to the kind of decisions that are now being made in agriculture and information concerning how ERTS and related data would fit into these decisions. Consequently, we begin with information concerning the goals and how the decisions relate to the goals. We also have done considerable work on how inter-regional considerations would fit into the model. Finally, our work during the past year puts us in a good position to apply the concepts of conflicting world views with respect to goals and the use of ERTS and related data in decision making.

## 2.5 ADDENDUM A: SYSTEMS ANALYSIS IN PUBLIC POLICY: A CRITIQUE

The table of contents below lists the topics discussed in Systems Analysis in Public Policy: A Critique by Ida R. Hoos, to be published by the University of California Press in May 1972.

### TABLE OF CONTENTS

- I. Survey and Perspective
- II. The Systems Approach in Theoretical Perspective
- III. The Systems Approach in Practical Perspective
- IV. Systems Analysis as Technological Transfer
- V. The Technique of Problem-Solving
- VI. Costs, Benefits, and Budgets in Education and Health
- VII. Information Systems in the Service of the Public
- VIII. The State of the Art of the Future

## 2.6 ADDENDUM B: STUDY OF CENSUS AND NOAA ORGANIZATION "MODELS" RELATIVE TO ERTS

Investigations concerning remote sensing data, when viewed as a system, are concerned with a broad scope of interest. The California project is concerned with many aspects of the problem including the utilization of the data obtained from remote sensing systems. This particular investigation is concerned with the dissemination of the remote sensing information, not for only experimental projects but for ongoing systems as well. Now is the time to begin the design of a national and international data dissemination program, by developing policies for the disposition of remote sensing data which in turn will guide the design of a bureaucratic structure. This investigation is not concerned with who physically shall control the bureaucratic structure (e.g., the Department of the Interior, the Department of Commerce, etc.) for this may be investigated by others. The particular policies under investigation concern:

- (1) Who gets the data?
- (2) Who pays for the data and how much do they pay?
- (3) In what form are the data made available?
- (4) How is it to be decided what information will be gathered by future satellites?

At first examination the answers to some of these questions appear to be self evident. However, a closer investigation shows that they may be very complex and, in fact, are the key points which

will determine the design of a bureaucratic structure. As an example of the first problem area, it may be determined that the information collected by an on-going Earth Resources remote sensing system is nonclassified and is designed for use by anyone who should request it for any purpose. An alternative view is that remote sensing data may very well infringe upon the rights of individuals, since information which will be gathered may be considered personal. The Census Bureau is extremely sensitive on this point and it is very careful to suppress individual information and not make it available. The same problems may well arise with respect to remote sensing data. Several interviews indicate that some persons who are knowledgeable in this area feel that remote sensing data should be released only to qualified and certified researchers who will maintain the confidentiality of the data.

One approach to the problem is to investigate existing agencies in order to determine their policies and how their policies may be adapted to the design of a new agency. The two primary agencies under investigation are the Census Bureau and the Meteorological Satellite System under NOAA.

The Bureau of the Census was elected to be studied as an existing data dissemination system because of many similarities with the ERTS System and because it has a long and involved historical development. The policies of the Census Bureau have been modified and adapted over the years to accommodate changes in the interpretation of our constitutional form of government and in the desires of the population. The

current policies which the Census Bureau are following and which relate directly to the areas under investigation are as follows:

1. The Bureau of the Census makes available in summary form to any and all interested parties any information which it has collected and suppressed with regard to individual information.
2. The basic expenses of the data collection of the Census Bureau are borne by the federal government. Individuals or concerns obtain this information for the marginal retrieval cost. Specialized services which are requested by individuals or concerns must be paid for by those individuals or concerns in their entirety unless, within six calendar months, additional individuals or concerns wish the same data whose cost is then prorated.
3. All information collected by the Bureau of the Census is available in many compiled sources and also in the original data format, but with individual information suppressed.
4. Prior to each decennial census and occasionally during other periods, the Census Bureau holds hearings in various locations throughout the United States. Interested parties are invited to attend these hearings and to discuss and make proposals concerning data to be collected during the forthcoming census. The Secretary of Commerce and his authorized representatives make the final decisions concerning the appropriateness of any such proposals.

The National Environmental Satellite Service is viewed as an existing service which is most directly related to the ERTS Program. The mission of the National Environmental Satellite Service is: "Plan and operate environmental satellite systems, gather and analyze satellite data and develop new methods of using satellites to obtain environmental data." The system is new, for the initial satellites which first carried experimental devices concerned with environmental data were launched in the early 1960's. The first fully operational satellite system was established by ESSA I and ESSA II in February



of 1966. Since that date, continuous weather monitoring has been available throughout the world. The satellite program is relatively young and the historical developments are very recent. The current policies of NOAA with regard to the questions under investigation are:

1. The information gathered by the National Environmental Satellite Service is available to all interested parties.
2. The secondary dissemination service is provided the data at marginal collection costs. Secondary dissemination systems are normally groups such as the wire services and other bureaus.
3. The National Environmental Satellite Service makes available pictorial displays of all of the earth's surface scanned by its satellites.
4. The National Environmental Satellite Service periodically holds hearings to which all interested parties are invited who wish to make proposals concerning information to be collected by future satellites. These recommendations are normally made by scientists and meteorologists. The final authority for the design of future satellite systems rests with the director of the National Oceanic and Atmospheric Association and his representatives.

The National Coast and Geodetic Survey also has a long and interesting history and there are some important uses which it has made of remote sensing data systems. The Coast and Geodetic Survey is primarily responsible for the collection and dissemination of information concerning the oceans, the shore lines and the adjacent land masses of the earth, particularly with regard to those areas within and which are closely influenced by the United States. It is anticipated that ERTS data will give further information concerning these areas of interest. A close examination of the policies of the Coast and Geodetic Survey system indicate that they would not serve

as a viable model for the ERTS remote sensing data dissemination system, though there are many similarities.

This investigation will view the ERTS remote sensing data dissemination system from a systems approach and careful attention will be given to the various components of the system, their identification and relative position within the system.

Various policies will be suggested which address themselves to the four major points in question and each policy will be investigated and carefully weighed as to its merits and potentials. There is no single criterion for measuring the appropriateness of the policies of this study for it is obviously a multiple criterion problem and in fact, there is no one "correct" policy or design. Recommendations will take the form of discussions of the potential merits and failings of alternative designs which may result from these policies. The criteria which will be used to evaluate alternative policies are:

1. Feasibility
  - a. Political acceptability
  - b. Technical
2. Gross Cost-Benefit Analysis Estimate
  - a. The values used will be clearly stated
  - b. The replacement of existing data collection systems will be reviewed
3. Consistency
  - a. Internal
  - b. External--with other governmental agencies
4. Clarity

5. Minimum necessary set of policies
  - a. Reasonable exhaustiveness
  - b. Minimum practical number
6. Justification
  - a. Fairness
  - b. Can it be successfully defended when attacked by the antithesis?

The literature search on this project has been almost completed and the investigation is underway. Numerous interviews have been conducted and various approaches to the problem have been analyzed. The design is now complete as well as the historical investigation of the models. Various competing policies are now being assimilated for investigation.

## 2.7 ADDENDUM C: DESIGN OF AN ERTS SYSTEM FROM AN INTERNATIONAL POINT OF VIEW

PPRO<sup>\*</sup> on the Irvine campus of the University of California is examining the pros and cons of various kinds of organizational mechanisms for distributing ERTS information and taking into account some of the more significant surrounding constraints that the organization may have to deal with or which may have to be dealt with by whatever agencies undertake to create the organization. In doing so we are mindful of the attention which NASA and other groups already have given to certain aspects of this question even to the point of establishing ERTS data reproduction facilities and distribution centers. We regard our work as being an extension of such existing efforts, particularly with reference to international considerations.

PPRO work at the present consists mainly of bibliographic preparation and data accumulation. To date we have combed most periodical references to artificial satellites and related areas. Specifically, this includes discussions of COMSAT and INTELSAT, meteorological satellites, and the several international organizations and symposia that are now, or will be, involved with the proposed global ERTS enterprise.

Since COMSAT/INTELSAT demonstrates the feasibility of an international syndicate for earth-related space uses, it is a fruitful commercial analog to an ERTS with global operations. Meteorological satellites and their organizational operation are a fruitful

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<sup>\*</sup>Public Policy Research Organization

operational analog, since their function more closely parallels that of ERTS than does the function of COMSAT/INTELSAT.

Questions which are now in the process of being explored are the following:

What is the best organizational arrangement to facilitate open accessibility of data and also guarantee security when required? What are the obstacles to open access to data?

Recognizing the controversy generated by the appointment by Congress of COMSAT directors, how can the issue of ERTS management and control be resolved with a minimum of disagreement among the parties involved? How can the question of ownership of a global ERTS system be resolved to facilitate optimum operation?

What contributions can the United Nations make to the smooth functioning of a global ERTS system? What should its role be, given the resources at its disposal?

Can one or more states/private enterprises make use of satellite-gathered data relating to the resources present in the territories of other states without their permission?

Can the slow process of international treaty approval be obviated by establishing a private corporation? What advantages and disadvantages does this approach have relative to using the State Department, the United Nations, or other public agencies? To what extent can some of the more significant disadvantages of a private corporation be mitigated by its charter?

If a private corporation is formed, will foreign nationals, companies, or governments be permitted to buy large blocks of stock?

Should ERTS become a self-sustaining financial entity? If so, how can it best do so?

Can Congress be expected to sustain the operation of ERTS solely because of the increased efficiency of domestic resource management which ERTS is expected to realize?

What funding conditions will Congress be forced to alter, given foreign pressure to internationalize the management of ERTS?

Must a global ERTS survey system assume the function of training technologists from various nations before there can be any appreciable economic application of the data?

Which users should pay how much for what services?

Does American technological superiority imply any social responsibility to disseminate ERTS data free of charge to the world community? Who should pay and who shouldn't?

Must the free transmission of ERTS data to nations be assumed as a return for the territorial invasion that results from ERTS operations?

## 2.8 ADDENDUM D: BEYOND BENEFIT-COST ANALYSIS

In this section Benefit-Cost Analysis as a method for evaluating ERTS is critiqued from two points of view. One is within the framework of B-C analysis itself and on the question as to whether all appropriate costs and benefits (including non-benefits) have to be included. The other approach challenges the appropriateness of the method for this type of decision even if an attempt is made to estimate all relevant costs and benefits. It is argued that ERTS will change the social conditions of the nation and is, accordingly, one which goes beyond B-C analysis. Methods to aid us in making judgments on values and whole ways of life therefore become necessary.

In our view the Earth Resource Technological Satellite (ERTS) is a socio-cultural as well as a technical-economic phenomenon. As with any technology, social and institutional changes must take place before ERTS can be introduced, accepted and become a part of the cultural fabric. As it is assimilated it will begin to weave its own warp and woof of values, expectations and aspirations. Any notion of benefits and costs must ultimately be based on the social-cultural milieu from which they derive and for which they are intended. Herein lies the major conceptual difficulty that faces benefit-cost analysis. It has no explicit methodology for handling social-cultural change.

To be sure the reflective B-C analyst considers the possibilities as to whether it is societal, regional, special interest group or

individual welfare that is to be maximized. However if more than one entity exists in any of the categories a problem of equity immediately presents itself. Whose welfare should be benefited more? The analyst cannot ignore this question in those cases where everyone's 'welfare' is improved or in the Pareto Optimal situation where at least no one's is impaired. For, much of one person's perceived benefit resides in his comparative well-being. If, for example, ERTS technology initially favors water, agricultural, energy and recreation interests more than it favors mining, land, and urban development interests, then a redistribution of wealth occurs and a conflict over values persists. Whether he likes it or not the B-C analyst has to take a position in the distribution of wealth debate. He essentially says that "those who are winners are more important than those who are losers." This it would seem is beyond his province and entitlement. Nothing in his method, position or credentials permits him to make such pronouncements.

Recently a method known as the "Delphi technique" has offered some promise in helping the analyst identify values. Members of a "relevant" community are pooled as to their preferences (and perhaps the relative 'weight' of their preferences). The logical union of these preferences is then formed, and the members are asked to re-evaluate this expanded list. The process is repeated through several interactions or until some degree of agreement or consensus is found.

But, does this Delphi method eliminate the problems mentioned above? No, because the analyst has selected a subpart of the



population to examine. If one resorts to the strategy of random sampling, then one assumes that there is a large, more-or-less homogenous population of human values whose characteristics are being estimated by the sample. But this assumption is a very shaky one. For example, the increase of "recreation benefits (that) will accrue if the levels of streams and reservoirs can be higher and steadier . . ." may be agreed to and valued highly by some delphi participants. But for some, water recreation means swimming; for others it means fishing; for still others it means motor boating and for others yet it means gazing at and contemplating a placid body of water. The actions necessary for securing the benefit for one conflicts with the enjoyment of the benefit for another. Even within the sample of respondents, therefore, a real and practical sense agreement did not exist. Indeed, if the analyst obtains too much agreement he is probably not asking a precise enough question. If there is anything we know about people, it is that they seldom fully share the same values nor do they pursue them in exactly the same or in mutually independent ways.

Of course the thoughtful B-C analyst is aware of these points and has often resorted to the assumption that all humans share in one basic value, namely, the economic. But here the analyst has simply placed himself on one side of a great historical debate: whether basic human values are or are not reducible to social economic values. It is safe to say that any simple version of the pro side of this

debate can easily be shattered by the very telling arguments of the con.

So, by beginning with the specification of objectives or goals as the dimensions of benefits, the analyst is seeking to determine something which, in the final analysis, doesn't exist or at least, qua analyst, is not within his purview to determine.

This limitation, however, may not be the most severe one the analyst faces. Let us, for the moment, assume that the analyst can uncover a tolerable set of objectives upon which to base his benefit analysis. Are they invariant over time? No, because once the process of realizing a technology has begun, the realization inevitably influences the human value system. The very act of commencing to secure benefits may change the nature of the benefits themselves. Also, what once took generations to change can potentially, in the 1970's, take place in just a few years. Communication, transportation and the sheer magnitude of most modern enterprises contribute to this rapidity with which value changes take place. ERTS will have this kind of value changing impact.

ERTS is really a social experiment, not just a technological one.

It will change personalities, social relations and institutions and create new values and outlooks on life. Not only does this qualitative shift in values bring into question the usual methods of measuring values, but, it also poses a more fundamental query: 'What is the relevant value system to use?' This is a question that translates into 'How should one view the whole system of which ERTS is a part?'

Churchman has suggested four concepts for valuing and hence assigning benefits and costs to social decisions. They are:

1. the extent to which a project suggests new means for achieving given ends;
2. the extent to which a project adds to our understanding of the relationship between means and ends and aids in discovering the most efficient means;
3. the extent to which a project facilitates co-operation between two goal-seeking entities within the same environment so that the act of A achieving his ends does not interfere with, but may, in fact, support B's achieving his and vice-versa;
4. the extent to which a project creates new ends.

Benefit-Cost Analysis stresses efficiency and as such falls primarily into category number 2. It receives only a modest score in category number 1. In most studies the primary focus of B-C analysis is to determine the most efficient alternative from among a set of existing or identifiable alternatives; it does not engage in inventing radically new alternatives, although sometimes its output may be suggestive in that regard.

The greatest shortcomings of B-C analysis lie in categories 3 and 4. The method patently ignores the resolution of conflict between competing end-seeking people, and the creating of new ends which they may seek. ERTS as a social experiment will create both cooperation and conflict. Often B-C analyses make implicit assumptions about categories 3 and 4. These systemic assumptions are in the process of being exposed, examined and reviewed. Our results will be reported upon quite fully in our May 1972 Annual Progress Report.

## 2.9 ADDENDUM E: SOCIAL APPLICATIONS OF RESOURCE INFORMATION

### New Internal Working Paper Series

1. On Comparison and Administration: A Philosophical Discourse, C. West Churchman, May, 1971.
2. Can a Manager Teach an Automated Information System?, C. West Churchman, May, 1971.
3. Systems Analysis and Organization Theory: A Critique, C. West Churchman, June, 1971.
4. Policy for Policy Sciences, C. West Churchman, July, 1971.
5. Operations Research Prospects for Libraries: The Realities and Ideals, or Strategies for Operations Research in Libraries, C. West Churchman, August, 1971.
6. Systems Engineering, Operations Research and Management, C. West Churchman, September, 1971.
7. The Measurement of Mood and the Mood of Measurement, C. West Churchman, October, 1971.
8. Management and Planning Problems, C. West Churchman, October, 1971.

## 2.10 ADDENDUM F: MANAGEMENT AND PLANNING PROBLEMS

### 2.10.1 Introduction

The purpose of this paper is to discuss the role of computers and information systems in management, both in the private and the public sectors. I intend to be very brief about the past uses of management information systems. The reader interested in a report of the current state of the art and the concomitant confusions can consult any one of a number of articles and books listed in the References.

At the outset there needs to be a discussion of the central concept of this paper, which really has no satisfactory label in the English language. The intent is to consider the way in which managers ought to interact with computers and allied information systems, but the word 'manager' in the English language is apt to connote managing large corporations in the private sector, whereas the intent of the chapter is to use the word manager in a much broader context. 'Management' is a concept which refers both to an intention and to an ability. The intention is to serve a certain group of people by changing certain aspects of society and its environment. The ability is an ability to choose among a set of alternatives, each of which potentially serves the relevant clients. Thus, 'management' refers to a large number of human beings and their behaviors: administrators in government, managers in the private sector, heads of families, and so on. Indeed, one can talk about the way in which an individual 'manages' his own life, since each one of us as a living being in various times of his

life is committed to serving both himself and others. We all believe that we have the capability of choosing between alternatives of our life patterns. As we shall see, this description of managers and management is a description typically used by one type of individual, whom we will refer to as the systems scientist, for lack of a better word. It may very well be that the systems scientist's concept of management is at serious odds with the concept of management as other people use the word. This is a point to which I will have to return subsequently.

One way to summarize the problem of the role of computers and information in management is to say that the problem is probably as broad and as deeply complicated as the problem of how one ought to manage. That is to say, no one has a clear concept of how computers ought to be used in the management process. But there are a number of different opinions which we will explore, some of them based on rather simplistic notions of management and management information systems.

#### 2.10.2 Routine Data Systems

It will be helpful at the outset to clear away one whole area of utilization of computers by managers. This is the area where routine requirements, either of a legal or bureaucratic nature, are virtually required of management. For example, in both the public and private sectors, the law requires certain organizations to collect information about expenditures and receipts, as well as to report on their assets. Similarly, there are legal and other requirements concerning personnel:

payroll, attendance, etc. This area of management information will be of minor concern in this paper, but some remarks should be made about it since it undoubtedly has been of major concern in the last decade.

As the computer became better known to managers, it looked as though it would be a panacea for the very irritating problem of collecting required data banks on accounts, personnel, and related matters. After all, the recording of payroll, for example, is apparently well laid out along manual lines, so that it appears that there would be no difficulty at all in simply translating the manual instructions into a computer program. Or, consider a radically different case, that of the settlement of interline accounts between railroads. This monthly procedure entails trying to determine what each contributing carrier should be paid in terms of a number of different regulations that govern the railroad industry. Normally the procedure entails a fairly detailed scrutiny of the route by which the freight was carried and the regulations governing the allocation of the customer's payments to the contributing carriers. Anyone experienced with this clerical operation would become fully convinced that it is completely routine, and that there would be no difficulty in getting a computer to do exactly what a clerk can do.

But the idea that one could put payroll of interline accounts onto a computer without much difficulty turned out to be naive in the extreme. In both cases there are a number of aspects which are peculiar to a given company, or to an industry, which are often not well understood.

It is no easy matter to make the computer behave as a clerk would do. Certainly the notion that one could find a universal "payroll package" was a faulty one. I suppose an analogy could be made between the use of the computer in routine data collection and the automobile in routine transportation matter. It simply took much longer for the public to learn how to use automobiles effectively than one would have expected; it certainly took a great deal longer for management to use computers in routine data collection matters than had been expected.

It seems safe to predict that over the next decade large companies in the affluent nations will have computerized most of their large-scale, routine data collection. It would not be safe to say that this is the most economical way of their conducting their business at the present time, but there is little question that over the years computer-based routine data collection will be standard policy and therefore "economical" policy.

But it also seems safe to say that small businesses in the affluent countries, and any kind of business in the developing countries, will have to wait some time before the computer becomes a realistic aid in their efforts. I know of only one computer company that has developed an interest in small businesses (SERTI in Paris). It still remains the case that most small businesses, for example, farmers, have a very unrealistic concept of profit and assets, and undoubtedly some kind of integrated computer system might very well help them to understand some of the basics of their business much better. The difficulty does not



lie in setting up a computer system that would serve a lot of small farmers simultaneously. Rather, the difficulty is that if the farmer is to utilize this type of system adequately he must go through a certain type of training. But the expense of this training may be of an order of magnitude well beyond the farmer's capability of paying for it. This problem of education for computer usage seems to be quite general. A large-scale, centralized computer might well serve a number of diverse customers, but the main expenditure lies in training the organizational personnel to utilize the computers properly and to have management understand the computer output. Large corporations and government agencies in affluent countries in non-depression periods can usually afford the training expenditure. We may, therefore, be witnessing another instance where a technology essentially belongs to the affluent few.

From the systems point of view, one might raise the question whether the advent of the computer in routine data collection procedures has resulted in the cancellation of a large number of jobs. I know of no study that has specifically addressed itself to this topic, but it is probably safe to conclude that the technological displacements associated with computers are no worse than those associated with other large-scale technical developments. For example, the change in national policy with respect to space exploration is probably much worse than any large-scale displacements resulting from computers.

### 2.10.3 Management Information Systems

We turn now to the major topic of this paper. Our concern will be what are called 'management information systems' (MIS). A review of the literature shows that MIS has been used in a number of different senses. These range all the way from the very simplistic notion that a management information system should contain 'all the information the manager needs' to fairly sophisticated information systems which are geared to the actual decisions the manager must make. For an example of the differences, see Ackoff (1967) and Rappaport (1968).

The distinction between MIS as used in this paper and routine data collection is that the MIS is primarily geared to managerial decision making. Hence, in order to set the stage for the discussion, it is necessary to discuss two kinds of systems, the management information system and the management system. The management system of an organization is a system by which decisions are made to change or not to change various aspects of the system. As already mentioned, a management system can be regarded as an organization which has specified goals that are supposed to serve a specified client. The system, which of course may be a single individual, is a 'decision maker' who has the power to change certain aspects of the social system. The management system also has components. That is to say, we can regard the system as composed of divisions, each with its own appropriate 'decision maker.' The system also has an environment which is outside the control of the manager (decision maker) but whose characteristics play a role in the success or failure of the organization with respect to its objectives.

The management information system, as viewed from the point of view of the management system, is a component of the management system whose purpose is to gather information which will best serve the informational needs of the management system.

#### 2.10.4 How MIS Ought to Develop: First Hypothesis

I'd now like to turn to a discussion of the future of management information systems, with specific emphasis on the desired social objectives of such systems.

To do this it will be necessary to talk not just about the systems but about the people in the systems and specifically about managers and about the systems scientists who attempt to design the management information systems for the managers.

This means that I am going to have to try to do something in this paper that has not, as far as I can see, taken place elsewhere, namely, to try to identify the kinds of people who are working in MIS technology and in particular the way they view the world and the value systems which they have come to regard as the appropriate ones. I have to do this because I shall be trying to develop the notion of what ought to be, rather than simply what one might forecast will be.

Now, the systems scientists have one value which is a prominent one in their approach to social systems, namely, that it is possible to be reasonable about society and its problems and that reasonableness can guide us in the selection of the methods by which we attempt to solve societal problems. To be sure, in the last two decades the concept of

reasonableness has undergone some considerable changes. For example, in the earlier days of urban planning the reasonable approach of the planner was the attempt to develop ways of manipulating peoples' lives so that the city could "grow" in some "successful" manner. But the urban planner has undergone quite a shift in his conception of his own role and what a reasonable approach to urban planning must be. The systems scientist (planner) has come to see that one cannot treat societal problems in isolation. They are interconnected in very deep and complicated ways.

The systems scientists have also gradually come to realize the value of participation in planning; in a changing society, it is reasonable to say that people have a right to expect that they will have something to say about what society does to them.

Finally, the systems scientist has come to see that he does not have all the information that is required to develop an accurate model of society and its environment. He's therefore at least paying lip service to the concept of social experimentation and adaptation. In some cases, a great deal of sincerity has been expressed about the need for wise social experimentation.

Nevertheless, despite the fact that the concept of reasonableness has undergone some changes in the last two decades, the systems scientist does maintain a fairly consistent outlook with respect to society, its environment, and the client whom the systems scientist hopes to serve. It is reasonable, he says, to assume that a society (a specific organization

like a city, or the Department of Defense, or a state, or a nation, or a whole world) is in pursuit of certain values or goals and that it has available to it certain resources which can be used in a variety of ways to attain these goals. One can judge whether or not the particular way a manager chooses to use a resource is appropriate by examining whether or not the utilization leads to a state of affairs that is an improvement for the appropriate client (e.g., the public); hopefully the ultimate state of affairs is as good as can be with respect to the client's interests. The recent emphasis on participation of the client in what happens to him is really no shift in this reasonable approach to society and its affairs, because the systems scientist has come to see that participating is a desirable social objective and that therefore he is obliged to consider this objective in his work.

It is, I think, safe to say that almost every systems scientist in the west today has arrived at some such attitude with respect to the world and therefore with respect to his job in that world. It's not necessary to demonstrate this point, except by some references to what has been written already in the literature. For example, when McLeod waxes enthusiastic about how systems scientists will have some impact on politicians, he tells us that "ideally our leaders should become futurists or futurists should become our leaders."<sup>\*</sup> This, of

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\*"International Cooperation," to appear in a collection of papers to be published by the American Federation of Information Processing Societies (AFIPS).

course, is reminiscent of Plato's plea that the leaders of society should be 'philosopher kings.' What is being urged is that our politicians adopt the perspective of society and its world that lies in the very reasonable perspective that the systems scientist brings to bear. Or, in the Daetz and Faulkner essay on population, we are told that Jay Forrester suggests that 'man's intellect cannot adequately grasp social systems structures which are by nature a multi-loop non-linear feedback' (italics mine). It's interesting to note in this regard that the phrase, 'by nature,' is supposed to indicate that the expert on non-linear feedback can see the nature of social systems structures far more clearly than a manager who has never been privileged to study multi-loop, non-linear feedbacks. No wonder, then, that Forrester can go on to conclude that 'government legislation is often inadequate, based as it is on inaccurate models.'<sup>\*</sup>

From these illustrations which are simply representative of thousands of such statements made by systems scientists, one can conclude that the systems scientist, who is himself a kind of "inquiring system," brings to bear on his study of the world a particular perspective which he truly believes to be the realistic and reasonable perspective. Indeed, it rarely occurs to him that there could be another perspective quite different from the one he holds which is equally reasonable and, in some sense, much more plausible to other segments of society. In a paper on medical systems,<sup>\*\*</sup> this point is brought out quite strongly;

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<sup>\*</sup>"Population Problems," to appear in a collection of papers to be published by the American Federation of Information Processing Societies (AFIPS).

<sup>\*\*</sup>"Biomedical Problems," to appear in a collection of papers to be published by the American Federation of Information Processing Societies (AFIPS).

the author claims that the doctor in the medical profession does not think in the same terms as the systems scientist thinks. No wonder the systems scientist is highly puzzled by the doctor's behavior and is apt to label it irrational (i.e., unreasonable).

The first hypothesis, therefore, of where we ought to be going with respect to management information systems says that where we ought to be going is where the systems scientist perceives to be the reasonable outcome of our efforts.

This hypothesis leads us to what could be called a 'working axiom' of the systems scientist, namely, that the successful management information system depends very strongly on how well designed is the management system. In other words, the systems scientist has gradually come to realize that the management systems with which he deals are poorly managed, and that the development of better management information systems by themselves cannot cure the ills of ineffective management that plague today's society. Thus the working axiom comes out as follows: if the management system is relatively ineffective with respect to its real purposes and its real clients, then no management information system by itself can expect significantly to increase the effectiveness of the management system.

It is necessary to call to the reader's attention that this working axiom is not obvious and has essentially risen out of the systems scientist's experience with the management of social systems during the past two decades. The working axiom is frequently alluded to in other

papers. For example, in his paper on economics, C. Wolf points out that, although computer technology can help in economic problems, he believes that the major solutions are very different from those opened up by advanced computer technology: a more active antitrust policy and a judicious use of liberalized commercial policy are "likely to be much more important in stimulating competition than are advances in computer technology."<sup>\*</sup>

The working axiom's statement that, given current managerial performance, information alone cannot greatly improve an ineffective management system, is quite contrary to much of the lore that is published in management journals. Many managers believe that if they could only get more accurate information their own decision making would thereby become far better.

There's no denying that one can easily concoct examples where information is the key factor in the ineffectiveness of managerial decision making. If the sailor on watch doesn't shout down to the captain, "There's an iceberg ahead!" or some similar piece of information, then the captain's management of the ship will be faulty, and if the sailor does so shout, then the captain's management of the ship may turn out to be very effective. But these concocted examples do not represent the realities of the management process. The ineffective management systems are not primarily ineffective because they lack certain kinds of

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<sup>\*</sup>"Economic Problems," in a collection of papers to be published by the American Federation of Information Processing Societies (AFIPS).



critical information. To the systems scientist, they are far more apt to be ineffective because the way in which the components of the system work together is ineffective, and one does not solve the coordination problem of the components simply by creating items of information. For example, the departments of a university typically work in a very ineffective way with respect to one another. One could not expect to solve this universal problem of universities by creating a central data bank which told any department how another department operates. To the systems scientist, the real reason for the lack of coordination of components of the system seems to lie in complicated political battles and not in informational vacuum.

#### 2.10.5 Data Vs. Information

The working axiom needs to be explained in greater detail. To this end suppose we center our comments around one very important application of computers to management decision making, namely, inventory control.

The problem of inventories is pervasive and occurs in both the public and private sectors. The social human being devotes a great deal of his time to collecting resources and storing them in suitable places against future needs. The basic and almost trivial management principle is that one cannot produce as the needs occur. One must produce ahead of time and make the resource available by forecasting what the needs will be.

Essentially, then, inventory control consists of attempting to store resources in such a way that they will be available on need and yet in such a way that one will not tie up a large number of assets in unused storage form.

Now at the outset it would seem that inventory control is a fairly simple matter from the point of view of information. What one needs to do is to obtain information about future needs for a resource, about the cost of storing the resource, and about the cost of shortage (i.e., the costs that are incurred when the resource is not available). There are certain other types of information, like lead time, that may also get into the picture. It would seem, therefore, that if a manager does not have adequate information about future needs, then he cannot control his inventory very well, and that if he does obtain this information and the other relevant information is at hand, then he can manage well. Therefore, it seems as though the working axiom stated above is false. It seems as though there must be many cases where inadequate forecasting is all that keeps management from successfully controlling its inventory.

The fallacy of this point of view, however, lies in the concepts of "needs" and "forecasting." A need is a stated requirement, but from the point of view of the systems scientist's concept of normative management (and here we are only concerned with the normative aspects of management) a need is either correct or not correct. Proper inventory control consists of trying to satisfy the correct needs and does not consist of satisfying incorrect needs. Therefore, the management system of inventory has to pay attention to those aspects of the total system which are generating the needs. If these needs are not being generated properly, then proper inventory control does not occur, no matter how accurate the data may be concerning incorrect needs. Too often in packaged inventory

control models that are available on computers, the package merely contains a statistical forecast of demand on inventory items and pays no attention whatsoever to the very critical problem of whether the demand is a proper one. An inventory package which satisfied incorrect needs is not controlling inventory and is, in fact, solving precisely the wrong problem. The management system of inventory, therefore, requires some analysis of the origin of demand and the design of the demand system.

The same remarks apply, of course, to the so-called costs of storage and of shortage. These costs arise from the way in which the other aspects of the system are designed, e.g., the relationship of the system to its financial subsystems or to its customers. Of course, the systems scientist may conclude that he can do nothing whatsoever about the demand. If he does so conclude, then he himself has made a managerial decision, which in effect says that the total management system is ineffective and that the systems scientist must operate as best he can within the ineffective system. If he makes such a conclusion, he is probably concluding that even if he does the best he can, his contribution to the total system effectiveness must be very small. This, then, is the spirit behind the working axiom, that the management information system by itself cannot improve the quality of the management system. If the management system is very ineffective, then the contribution that the numbers make is not very great, according to the working axiom.

The discussion can be illustrated in terms of economic research. Economists attempt, often via the computer, to collect and store significant data about economic conditions and processes in regions and

countries and throughout the world. It is important to notice, for example, that input-output analysis does presuppose that the "inputs" are the proper inputs from the point of view of the total system, just as it presupposes that the outputs are correct, if managerial decisions are to be made from the input-output analysis. Of course, a great deal of economic analysis is not conceived by the economist to be anything more than a description of how the system is actually working, and economists often attempt to avoid the pitfalls of making specific recommendations on economic policy from their own analysis. Since, however, in this paper I am primarily concerned with the manner in which computers, and specifically management information systems, ought to be helping management in its decision making, then it is essential to point out that the simple amassing of large data banks, no matter how impressive in terms of size, may be completely irrelevant in terms of trying to use the data banks for the improvement of social conditions.

#### 2.10.6 Improved Types of Management Systems: A Thesis

But it would be incorrect to conclude that MIS from the systems scientist's point of view is only a trivial part of the management system. As the management system becomes more effective, then MIS can play a very central role.

In order to understand this remark and, therefore, to become clear about where the systems scientist hopes that tomorrow's systems will be, it is necessary to talk about how the management system can become more "rational" (i.e., reasonable).

In this chapter, a number of suggestions have been made as to the manner in which social systems can be better managed. These suggestions include concepts like participation, social experimentation, the extensions of the total system concept to the interrelationship of problems rather than the segmentation of problems, and so on. It will be helpful to recapitulate what many of the authors have had to say in terms of a typology of management styles which is supposed to reflect a normative ranking of the styles. That is to say, one proceeds from the fairly primitive, ineffective management style to the more sophisticated managerial style which the systems scientists advocate.

This typology says that one can describe management systems in terms of three types: the reactive, the planning, and the "learning."

In a reactive management information system, there is a very strong agreement on the part of the managers as to the nature of the business that they are in and the system boundaries, as well as the role and organization of the components of the system. When I say that there is a strong agreement among the managers, I mean that management is not interested in raising the question of the nature of their business, or the components, or the system boundaries. Consequently, the manager of the management information system has no opportunity within this context of raising such questions.

In the reactive management information system, furthermore, there is a minimum of interest in long-range planning. The management information system is regarded to be one that will enable the managers to

react effectively to what goes on in what they perceive to be their environment. This does not mean that the reactive manager is indifferent to the future, but it does mean that he sees no great point in pouring a lot of money into long-range planning and forecasting, given the uncertainties of his environment and his urgent needs to be able to react to the crises as they occur day by day. Consequently, the charge of the reactive management system to computerized MIS is that the MIS collect those kinds of information which will enable the manager at least to appear effective in meeting the challenge of the day-to-day crises and problems. The main point about the reactive management system is that it takes each problem within its own context and is not interested in seeing how different problems are related, one to the other, or the general framework in which problems arise.

In experience, reactive management systems appear to require rather large data bases which are closely related to the routine data bases. In many cases the chief concern of the reactive management system is to be able to respond to queries that are posed to it by its clientele or by financial companies, government agencies, etc. For example, in a research and development organization, the manager of the project in a highly reactive management system may have to respond to queries from top management about manpower on the project, about the present state of the project with respect to its explicit goals, and so on. An MIS system, in such a reactive management system, would therefore be one in which the project manager can turn to the computer and query it concerning

manpower requirements or project status requirements. It is important to note that in reactive management systems, the environment is taken as a given and a given that cannot be well predicted. The system boundaries are well laid out and the manager is not responsible for trying to change what goes on outside the system. The key word is "input."

We can find many cases where authors have reacted negatively to reactive management systems. Daetz and Faulkner, for example, point out the extreme danger of letting the population question lie in the hands of a reactive management system which waits to see what happens to the population explosion. To the reactive manager, if there comes the point where millions of people die of starvation or of mass crowding, then at that stage in the game it will be necessary to intervene. He believes that famine, wars, or just a change of values with respect to procreation may make the population problem go away, as so many social problems have in the past. To the systems scientist, this way of regarding the population problem displays a very ineffective management system.

Of course, the systems scientist does not believe that reactive management systems are universally bad. In times of crises where changes are occurring so rapidly, a reactive management system may very well turn out to be the best one, as, for example, in the case of earthquakes or large fires or plagues. But, in general, the systems scientist tends to regard reactive management systems, even when they are best, as a result of poor managerial planning in the past.

Thus, according to the working axiom for the systems scientist, the MIS of a reactive management system will contribute very little to the real system performance, even though it often may appear to be highly effective.

The second type of management can be called "planning." Here again the management is largely agreed on the business that they're in, as well as on the system boundaries. Their chief concern is to try to predict how the environment will change and to decide ahead of time what kinds of reactions they should prepare for these changes.

Planning management systems have been discussed in a number of places throughout this paper, wherever, for example, it has been suggested that one can extend man's capability of forecasting by means of computer technology. The implication has been that these extensions will be especially useful in strengthening man's ability to plan. Again, in discussions of gaming and simulation, it is argued that one can capture the real nature of certain aspects of the social system and understand, say, the competitive environment, either in the private sector or in the international scene. As a result, we should be far better able to understand what the future will look like and therefore plan in a rational ("reasonable") fashion.

In the past, there has been considerable activity in trying to develop computer bases for planning management systems. In the private sector, these generally consist of forecasts of changes in consumer behavior, of economic trends, and the like. In the public sector, for example, in comprehensive health planning, the emphasis



has been on trying to forecast what health needs will be and the kinds of services that will be required in order to meet them. The real emphasis, therefore, in planning management systems is on the ability to forecast, and various kinds of forecasting techniques have been generated. Among these are the Delphi technique (Helmer, 1966) and various kinds of statistical methods.

One area where the systems scientists are not in agreement with respect to planning management is the value of simulation. Some scientists seem to be quite sold on its usefulness. The attractiveness of simulation technology, which apparently provides the scientists with the capability of representing fairly complicated systems, has lured many a systems scientist into trying to sell management on fairly large-scale computer simulations. On the other hand, many argue that it will be some time, if ever, before simulation really plays a significant role, partly because it is so difficult to know which aspects of the real life situation should be included, but also because the whole basic mathematical technology of simulation has not been well explored. There is a further difficulty, which I find to be basic in all systems science work, namely, the difficulty of really making it clear what we mean by the concept of "X simulates Y." The great difficulty I have found in both modeling and in simulation is some clearer explanation of what it is that the scientist thinks he is modeling or simulating. This difficulty, of course, goes back to the very foundations of systems science. As I illustrated earlier, the systems scientist is apt to say that reality is "by its very nature" so and so, without realizing that his description of what

reality is comes out of his own approach to reality and can scarcely be said to be shared by all individuals who live in the social system.

The third type of management system is one in which the agreement about the real purposes of the system as well as of the client does not exist, and the management system is regarded to be one which is trying to understand more deeply its real purposes and its real clientele.

This type of management system might be called "learning management." MIS systems for learning management systems will have to be radically different from both the planning and reactive management systems. In particular the emphasis will not be on large masses of stored data, but rather on a kind of experimentation. The basic meaning of experiment is a "systematic method of learning." Experiment is not restricted to the method of simply changing a variable and looking at the results, since this method is highly restrictive and probably not applicable to social organizations.

I know only one example at the present time of a real learning MIS associated with learning management. This is a corporation which has a fairly sizable operations research group. Here the operations research group is not regarded as a staff which "solves" crisis problems, but rather as an integrated aspect of the total learning process of management. As a consequence, a very important part of the OR study is to relate the study results to other problems so that the results are a much more integrated model of the total system. There is a continuing question of where the system is going and what

type of clientele the system should be serving. In the learning type of management, the manager regards himself to be an "historical man" trying to learn from what has occurred before in order to pass this learning on through his own decision making in an enriched fashion to his successors.

As has been mentioned in other places, the concept of learning management also includes the concept of participation, since, as I mentioned, the systems scientist has come to conclude that participation is a very essential social value. The experimenters, therefore, are not to be viewed in the typical way in which experimenters work at a laboratory table. At the laboratory table, the experimenter is, in some sense, independent of that which he is observing. The notion of objectivity in classical science arose from this independence of the observer from that which he is observing. However, in learning management, neither the managers nor the systems scientists should regard themselves as independent of the social systems within which they live. The idea is that everyone is, in some sense, an experimenter, and that the scientist only plays one role in the total system of experimentation.

#### 2.10.7 Management by Everyman: The Antithesis

In his Phenomenology of Mind, Hegel develops a process of philosophy in which he presents a very plausible view of the world (which we can call here the "thesis" in the light of Hegel's later work). Hegel then argues for the thesis and, in a very subtle and ingenious

fashion, one finds that the strong argument in its support leads one to quite an opposite viewpoint of the world which we can call the antithesis. The whole point of the Hegelian methodology is not simply the contrasting of different points of view, as happens, let's say, in advocacy planning, but rather the total process of showing how, within one view of the world, there are the ingredients of its opposite.

What all this bit of philosophizing means with respect to our discussion is that, if we look at the world view of the systems scientist and try to develop what it really means, we begin to see that there is indeed an opposite and antithetical world view which contradicts in some significant sense what the systems scientist believes.

Systems science would have been in a very comfortable position could it have defended planning management as a successful method of managing. In planning management, all of the pieces seem to fit together remarkably well. One tries, as a planner, to understand the real clients of the system and then to understand how the system, which is controlled by the decision makers (managers), can be used to serve the client by means of making forecasts of how the environment will change. The role of the MIS in such a system seems clear enough. One tries to develop a model which will display alternative decisions of the managers, will predict how each decision will come out, and, by evaluation techniques, will tell how well or ill the

client was served by the specific potential managerial decision.

But since, in some important sense, planning management is not effective, in that attempts to make even moderately good forecasts seem doomed to failure, and since the choice of the set of values to be maximized is so uncertain that the planning management style is bound to run into the difficulties of serving the wrong client, then the systems scientist has to turn to what he thinks is an expanded version of his own philosophy, namely, learning management. But here he has laid the groundwork for his own downfall. Learning management argues that social experimentation is essential and that one must, in the process of experimenting, regard everyone as both experimenter and as subject.

But if this point of view is taken seriously, then what has become of the systems scientist and his capability of understanding the system? Apparently, this antithetical viewpoint says that everyone in society has a viewpoint of how society works. The systems scientist has his viewpoint, which may be Forrester's non-linear, negative feedback system, but the particular academic capability of a systems scientist to view the world does not put him in any privileged position with respect to how the system "really" works.

So we seem to arrive at a position which is antithetical to that of the systems scientist. No longer can we say that, "Social systems structures are 'by nature' multi-loop non-linear feedback systems." We can say that they are so "by Forrester's nature." On the other hand, someone who has lived his life in the ghetto and has seen

poverty in the form of direct experience also sees what the social system is "by nature," i.e., by his nature.

Furthermore, the problem of different perspectives is not necessarily solved by social experimentation. For the pragmatists, one poses a hypothesis and then sets about trying to test it by seeing whether a particular policy "works out." But if there are different perspectives of what the social structure is "by its very nature," then surely there must be different perspectives as to whether an experiment has, indeed, "worked out" successfully or has "utterly failed."

#### 2.10.8 Summary and Conclusions

For the author of this paper to recommend social management planning and research as well as cost effectiveness would be to ask him to play the role of the systems scientist, since systems scientists see the world of society in terms of problems, pitfalls, and expected cost effectiveness. This is how their inquiring system works. There would be no great difficulty, and indeed the literature is replete with examples, in trying to show how a cost effectiveness study should be made for an organization that is planning to develop an MIS. One tries to design an MIS to so improve management effectiveness from the systems scientist's point of view that it's far more beneficial than the cost of installing the system.

If one goes on to discuss recommended standards for scientific study of the human use of computers in the social problem area, one

would then try using the classical methods of science to urge that the systems scientist maintain as objective a position as possible: that he try as best he can to keep his own preconceptions and value system out of the picture, that he try his very best to see what "actually" happened, and that whatever he wanted to happen does not influence what he sees to happen.

However, if we take the antithesis that has just been developed, we can see that the systems scientist cannot conceivably keep his own preconceptions out of the picture, because he views the world in a certain way, and he takes his view of the world to "represent reality." But his view of the world is no more or no less valuable than the view that someone else may hold who is not a systems scientist. It is apparently not correct to say that management consists of maximizing cost effectiveness. This is how the systems scientist sees management, but it is certainly not the way in which most managers perceive their role, as anyone knows who has conversed at length with managers.

Can one draw any conclusions, then, in the light of such a devastating antithesis?

The spirit of dialectical reasoning argues that all approaches to the betterment of society demand different perspectives. One can become quite negative about the role of computer and computer-based management in today's society, just as one can become very enthusiastic about it. The philosophical point to be made is that man matures to

the extent that he can begin to appreciate a perspective of society which is different from his own. 'Appreciate' is a term which tends to be rather watered down in its meaning. In its richest and most powerful sense, it means the capability of putting yourself into some other person's perspective and living the belief in this perspective. To the systems scientist, this would imply quite a revolution. It implies that he should have the capability of truly perceiving what it means to be a manager who does not believe in maximizing cost effectiveness, in modeling the system according to feedback principles, cybernetics and the like, who does not believe in social experimentation, whether it is participatory or not. It means being able to see that 'participation,' for example, is simply a gimmick by which one group of people tries to put over some of their ideas on another group of people. If I want you to do what I believe to be the correct thing to do, what I'll try to do is get you to participate in the decision that I've already made. Of course, the outraged systems scientist may point out that he does not mean by 'participation' a deceptive scheme for fooling the public. But the wise manager who knows about managing through direct experience knows very well that this is exactly what happens to so-called participatory schemes. They are used as a device by which one group of people try to put over something on another group of people.

The dialectical process is an optimistic rather than a pessimistic one, at least in the context of this paper. The dialectical



process, it should be pointed out, is not an attempt to destroy knowledge or even a sense of deeper understanding. All dialectical processes presuppose certain features of the world, which presuppositions, of course, may be wrong, but the process exists from the expectation that they are correct. In this case, the dialectical process is based on the notion that deeper appreciation of other perspectives is one of the most important requirements for management information systems of the future.

Thus, though I cannot make a forecast about where management information systems will be, I can say that I have the faith and hope that management information systems of the future will greatly enhance man's capability of appreciating his fellow man's perspective of what the social being is "by its very nature."

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(The letters that follow the citations refer to the type of article: A is research-theoretical, B is philosophical-evaluative-critical, C is practical-technical, and D is collections.)

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## 2.11 ADDENDUM G: NASA/ERTS ACTION RESEARCH EFFORT: A FIRST LOOK

### 2.11.1 Concepts

There is adequate literature to support the assumption that individuals' cognitive organization or perceptual sets differ and are dynamically linked to organizational and behavioral variables. Additionally, organizational and structural variables define environments which support differing organizational and perceptual sets. The validity of these assertions has been well documented in the writings of Rokeach, Menzies, Trist, Marcuse, McWhinney and others as indicated in the bibliography at the end of this paper.

The way that man thinks about earth resources is of particular importance in determining the use to which ERTS data will be put in the management of earth resources. This means that we must look at the psychology of resources as well as their physical characteristics. Of particular importance is ego functioning which is the intervening organization between organismic (id or pleasure systems) and environmental processes. Within an open system context, the ego regulates conflicting preferences; its growth regulates man's ability to deal with his environment and provides the increasing degrees of flexibility that is required to live with the turbulent environmental events of our time. Moreover, the ego defines our identities. Bion has applied the Freudian concept to the group. We would like it to be applied to the wider social field--that of social networks for resource management.

Moreover, it is natural to address these issues at the present time because ERTS itself is partly a process of technological change. ERTS will induce structural, personal and task changes within the fragmented resource system, as indicated by the writings of Taylor and Leavitt. In a previous paper (Lewis, 1971) I have discussed several organizational and structural management modes for the integration of ERTS into resource management. This paper also discussed the role of perceptual sets and cognitive organization as they relate to organizational structure and practices. The proposed action research (or more commonly called applied research) phase of our ERTS effort will begin by looking at the structure of our perceptual sets or cognitive organization vis-a-vis our beliefs about resource management. This will be accomplished by administering relevant psychological and attitudinal measures and then developing a taxonomic structure of cognitive organization. The methodology which we plan to use is as described in my paper entitled "On the Structure of Student Identity, Progress Toward a Reflexive Social Environment."

Our research hypothesis is that attitudes towards resource issues are less based in reality than they are in the core or central belief structures or world views that an individual holds. This is partly indicated in McWhinney's study of the national foresters. If this hypothesis is true, a taxonomic cluster analysis should reveal a structure in the attitudinal and psychological space.

After refinement of this technique it should be possible to reduce our instrumentation to a more refined set and develop an applied

instrument. This instrument could be published as part of our text for resource managers. At this stage our previously collected pool of data would be again useful.

An action research chapter in the text could aid the manager in understanding the importance of values in general and as they pertain to the making of earth resource decisions. Moreover if the results of the applied research instrument could be fed back to the UC/NASA project we could supplement this data with behavioral and structural variables (see James Taylor's work). Then we could develop an introspective shadow system to evaluate the value and impact of ERTS and ERTS type programs in a new way. This later proposal is currently in the speculative stages. Our current concern is to get the initial psychometric and attitudinal survey under control.

#### 2.11.2 Activities and Progress

The major theoretical view has been completed and is in draft form. This draft looks at the role of ERTS and ERTS-class technologies in the managerial and social world. The proposed action or applied research effort will build from this and the other papers our group develops.

The next step is to develop attitudinal measures from these papers and to construct an appropriate psychometric instrument. The development of attitudinal measures is relatively direct. Currently we are reviewing the existing instruments.\*

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\*The COMREY scales, the POI and OPI as well as several other sets of scales.

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## 2.12 ADDENDUM H: AN EARTH RESOURCE DEBATE

### 2.12.1 Introduction

#### Prologue

What is the true value of ERTS? There is no ultimate answer to this question but it is important to consider how one might go about answering it. Some would say that the answer is essentially simple but computationally insuperable. That is, in principle all one need to do is to calculate the benefits or savings accruing from snow pack estimation, more efficient water management, blight detection, forest fire detection, new mineral discovery, improved cartography and land use mapping, and so on for each application. Then, merely sum up the benefits over all applications and by subtracting the actual and opportunity costs obtain a figure representing ERTS' value.

But others, on second reflection, find that the answer is more elusive and complex than that. Such a simple method raises serious doubts. When one takes a broad view of resource and environmental problems (the problems which in the long run ERTS is to help us to solve) one sees how finely these problems are interwoven with our governmental, industrial, and cultural institutions.\* The very way that we think and live and view the world is an integral part of the resource problem. If we can only find the right perspectives and institutions for nourishing the earth and insuring its survival,

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\*See "Beyond Benefits and Costs" by R. O. Mason.



then in a most essential way the resource problem will have been solved. A "solution" of this type is not measurable in Benefit-Cost terms, since Benefit-Cost analysis must assume certain institutional frameworks to make its procedures work.

However, there is immense value to be gained if we can find the right perspectives and institutions to aid man in solving the earth resource management problem.

There are three fundamental components to the earth resource management problem. First, there is the physical nature of the earth itself. Second, are the institutions, that is the laws, customs, practices and organizations, that man has devised for dealing with the earth. And, finally, there is the psychological outlook or perspective on the earth that each person, especially those in decision-making capacities, possesses. Each of these work together to determine the final dispensation and utilization of earth resources. Disfunctional uses, such as pollution, result from breakdowns or misunderstandings in all three dimensions.

If the ERTS program is to achieve its ultimate goal of solving mankind's food, water and mineral resource problems, it must deal with all three components of the earth resource management problem. The University of California Integrated study takes this perspective. While the bulk of the effort is directed toward determining how ERTS can provide better information about the physical nature of the earth, the social science group is addressing the other two dimensions of the

problem. Studies are currently under way which look at the questions of what kinds of organizations and institutions will be needed to deal with ERTS data and as to who should be involved in making earth resource decisions. This study is concerned with the psychological perspective man uses to guide him in organizing ERTS data, developing institutions and carrying out decisions.

Perhaps the most intriguing thing about the ERTS program is that it shows great potentiality for producing value in the sense of developing new perspectives on the earth. To be sure, there will be cost effective "applications," but these will flow naturally from the creation of a more lasting impact--a sobering realization of man's place in this "fathomless universe." (Whitman, "O Captain! My Captain!") The astronaut's descriptions and the awe-inspiring space photographs perhaps only herald a new world view to come. At least, there is some evidence in this regard. Take, for example, John Caffrey's letter to the editor in Science (March 20, 1970) in which he related the profound effect that the space photographs had had on him and then went on to say:

"Looking at the blackness beyond the sharp blue-green curve, trying to see even the place where the thin envelope of atmosphere and the solid earth meet, the curious word 'fragile' comes to mind. To be on Earth and think of it as fragile is ridiculous. But to see it from out there and to compare it with the deadness

of the Moon! I suspect that the greatest lasting benefit of the Apollo missions may be, if my hunch is correct, this sudden rush of inspiration to try to save this fragile environment--the whole one--if we still can."

Such are the potential benefits of ERTS; but, more importantly, this new perspective sheds new light on our opening question. The 'true value' of ERTS is not now of primary concern, rather, the question becomes "How can ERTS best be used to secure the value inherent in a more appropriate perspective on the earth?" What follows is an initial response to this question.

#### Method

ERTS imagery is only data--a set of basic observations of the world. Information is the "meaning" one derives from data. In order to produce information the data must be interpreted from some perspective or point-of-view. Data itself is inert; but, information becomes the basis for action. It is information that determines what decisions will be made and what actions will be taken. Any notion of value must be based upon total short and long range effects of these actions. Consequently, it is vital that we always consider whether the proper point-of-view was used to interpret the data as well as the adequacy and completeness of the databank itself. This is the only way to evaluate the ERTS program in any ultimate sense. This kind of evaluation will require an approach which is different from that employed to review data capturing and processing systems, because perspective or points-of-view are psychologically based.

NASA-sponsored research has led to the development of a new approach for exposing and examining points-of-view or "Weltanschauungen." In this approach, which is dialectical in nature, the data is systematically and logically interpreted from two opposing points-of-view which are in turn debated for the manager. The manager, then, must reflect both on the data and the point-of-view. The assumption is that upon witnessing the thesis-antithesis debate the manager forms a new broader, more encompassing perspective from which to view the data and the situation--the synthesis. In the context of the ERTS program this synthesis may result in a "better" way of viewing earth, one that pressing contemporary environmental, resource and population problems seem so desperately to call for.

The dialectical method requires the determining of opposing positions, the writing of empathic scenarios for each, and the placing of these positions into conflict over the data and issues via debate. The next section represents the beginnings of such an Earth Resource Debate.

#### 2.12.2 The Debate--An Illustration

##### Background

Our studies have shown that one of the early and perhaps most productive uses of ERTS will be to prepare comprehensive and comparable land use data. This data will then be interpreted by policy-makers to evaluate past usage and to make decisions about future usage. These evaluations and decisions will depend principally on the perspective they take in interpreting the land use data.

In order to expose these perspectives for conscious consideration a debate has been prepared between policy-makers possessing two different points-of-view. The sample data for this debate shows land use trends in Los Angeles County from 1940 to Present and as projected through 1990.\* In the future one might assume that this data would be produced from an analysis of ERTS imagery. Overlaying the photographic image would be a land use map prepared by computer analysis of digitized information from various sensors and augmented by inputs from trained human observers. However for the present we will use the available data as the basis for the debate. The data is displayed in Table 2.5

#### The Debate

Two policy-makers--Adam and Bud--debate the "correctness" of this land use policy by interpreting the data from their respective points-of-view. Adam begins.

Adam: Well, our land use policy as reflected by this land use data looks pretty good to me. From the standpoint of regional and national goals it demonstrates much of the great accomplishment of man. We have identified great new resources and have been able to employ them for the betterment of our ever growing population. Just look at the

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\*The source of this data is a short study prepared by Herbert Libow. The study revealed a definite lack of consistent, coherent and comparable land use data for L.A. County over the last 30 years. Our other research suggests a similar lack of data for such important areas as the coastline. This is a problem that ERTS will help to correct.

TABLE 2.5: LAND USE TRENDS IN LOS ANGELES COUNTY, 1940-1970

TABLE 2.5a

<u>LAND USE (1,5,6)</u>		<u>1940</u>	<u>1970</u>	<u>1985-90</u>
Urban used (4,16)	southern county	25.1%	73.6%	82.0%
Urban vacant (3)	" "	10.1%	5.3%	
Non-urban used (4)	" "	45.3%	7.3%	
Non-urban vacant (3)	" "	<u>19.5%</u> <u>100.0%</u>	<u>13.8%</u> <u>100.0%</u>	
Urban	southern county	35.2%	78.9%	
Non-urban	" "	<u>64.8%</u> <u>100.0%</u>	<u>21.1%</u> <u>100.0%</u>	
Used (4)	southern county	70.4%	80.9%	
Vacant (3)	" "	<u>29.6%</u> <u>100.0%</u>	<u>19.1%</u> <u>100.0%</u>	

TABLE 2.5b

<u>LAND USE (2)</u>	<u>1940</u>	<u>1960</u>	<u>1970</u>	<u>1985-90</u>
Recreation & parks (5,7,8)		**0.83%	1.6%	2.3%
Agriculture (5,9)		9.2%	3.6%	
Crop acreage (5,10,11)	12.7%	5.8%	3.1%	2.3%
Range land (5,12)		7.9%	8.0%	
Freeway mileage (13): in miles	6		405	1,045
Sand, gravel production (14,15): in millions of tons	*11.1		23.2	
Gold production (14,15): in \$	258,000	**7,200	**3,200	

\*earliest available information is dated 1947, however trend line indicates that 1940 production is about 7 million tons.

\*\*estimated from available data

#### FOOTNOTES FOR TABLE 2.5

1. The figures represent the percentage of southern Los Angeles County acreage devoted to the particular land use.
2. The figures represent the percentage of Los Angeles County acreage devoted to the particular land use unless otherwise indicated.
3. "Vacant Land" has the possibilities of future development.
4. "Used Land" has minimal possibilities for future land development and may or may not have a current land use. Most land in this category is in use. Vacant land and used land are mutually exclusive categories.
5. Revised Land Use Acreages by Statistical Area, Los Angeles County Regional Planning Commission, April, 1971.
6. Land Use Survey, Los Angeles County Regional Planning Commission, July, 1940.
7. Building for Tomorrow: The Community Improvement Program for Los Angeles County, Los Angeles County Department of Parks & Recreation, 1957.
8. Los Angeles County Regional Recreation Areas Plan, County of Los Angeles, 1965.
9. Land Uses, Los Angeles County Regional Planning Commission, 1960 (based upon Los Angeles Regional Transportation Study and U.S. Bureau of Census).
10. Southern California Agriculture: 1969 in Review, Los Angeles Regional Chamber of Commerce.
11. Southern California Agriculture: A Look Ahead to 1970 and 1980, Los Angeles Chamber of Commerce, 1961.
12. 1970 Crop & Livestock Report, Los Angeles County Agricultural Commissioner and County Veterinarian.
13. Verbal information obtained from Los Angeles Regional Planning Commission, Mr. Ron Mayhew, September, 1971.
14. Mineral Information Service, V.21, 1968 and V.6, 1953.
15. California Journal of Mines, V.50, nos. 3 & 4, 1954.
16. 1990 Land Use, Los Angeles County Regional Planning Commission, September, 1971.

extent to which we have been able to expand our cities as reflected in the increased urban usage data. This means that more people may have their own private home and their own place to work. There is smog, crime and some congestion to be sure but we are making progress and our agriculture land is still adequate to satisfy food needs for some time to come.

Contained here in this single table is a message of great inspiration. We have discovered our earth, subdued it and put it to work for us. Truly earth is now resting comfortably within the dominion of man.

Bud: Oh, the treachery of it all, Adam. The data shows that our obvious policy has been to continue to consume and destroy our land and its resources through too much urbanization. Man can never really be superior to his environment, he's a part of it. What the data shows is that we are in the process of breaking the basic harmony which man must have with his world. Man is such a recent arrival here on earth, a few thousand years is nothing considering the billions that the earth has been around. Don't our predecessors, successors and partners have rights? Flora, fauna and minerals have a rightful place in a harmonious world, too. We are offending these rights and may not live to regret it.

Sure, we derive a lot of pleasure and comfort today from our expansive sprawling urban areas, the products of our mines, our transportation system, and so forth; but the cost of depleting our



environment is so high. We must learn to "give and take" with nature, take a little "bitter with the sweet," if Man and this earth are to survive.

Maybe now is the time for man to start looking inward a little more to find himself and his place in the universe. Earth is not an object to be conquered, but a partner with whom to live. If Man could only understand this he would learn to understand himself. And, after all that's the real purpose in life.

I believe that 73.6% of our land in urban usage is far too much. The projections are for it to get worse. Let's cut it down to 20% and let's cut down on the transportation usage as well. Return it all to wilderness where it belongs.

Adam: Come on now, Bud. We have got to use our environment to our own advantage. Nature changes the environment every day of our lives, doesn't she? Why shouldn't we change it? Make it work for us? Besides, I'll never understand your concept of returning to wilderness. Do you mean that you want us to take large sections of land and just set them aside, never to be touched evermore?

Bud: Certainly.

Adam: How ludicrous. I agree with you that we must plan the ways by which we use our land very carefully. We have made mistakes in the past and chopped up wilderness areas much too fast and too rambunctiously. Certainly we aren't making the most efficient use of what we have. Some

re-alignment and forethought are most assuredly needed. But to return to primitive times? Ridiculous!

In my view, the best land use principle is quite simple. Take a region of land. Survey it well and make a comprehensive plan for its use. Then make part of it accessible for Man's use and part of it inaccessible. Don't touch the restricted portion until it is absolutely necessary. The 1990 projection seems consistent with this kind of planned land use policy.

Bud: Would you preserve those restricted portions forever?

Adam: No, not forever. You can't take a large area of this country and keep it the way it was a thousand years ago. Nor can man afford to retreat from the most productive lands. We cannot continue to deny man's urgent needs by trying to create useless wildernesses.

Bud: Wilderness is not useless. A wilderness area is worth saving or creating in its own right. Man has no business disturbing what lives and resides there naturally. The pollution problem has shown that it doesn't take much to destroy ecological balance. In other areas our land use policy is literally driving some species prematurely into extinction. That's just not morally correct. They are partners in the universe. They have their rights, too. Only the forces of nature can sentence a species to extinction. It is not within man's moral purview to do so.

--In the complete draft, the debate on "whose values?" then goes into the details of the policies worked out by each side in terms of its worldview and the data bank.--

The research team devoted a good deal of time trying to determine land use data as a basis of this paper. A separate paper has been prepared entitled "Some Comments on Land Use Data and the Role of ERTS in Land Use Classification." This paper which compares different land use classifications will also be available in the working paper series. The paper argues for the non-existence in practical terms of comparable and comprehensible land use data, and attempts to develop a methodology of land use computations.

## 2.13 ADDENDUM I: AN INTERDISCIPLINARY APPROACH TO SCIENCE AND SOCIETY: THE EXPERIENCE OF A DECADE REVIEWED

An indepth study of the establishment, development, and contributions of the Social Sciences Group and its out-reaching, wide-ranging Seminar is not simply to rehearse and rehash the past. Their history, which reflects an interesting chapter in NASA's university relations, provides fascinating insights into little known dimensions of the national space program, for, contrary to popular misconception, this does not consist solely of a series of glamorized, spectacular events. Much hard work in the laboratories and at the benches of scientists and technicians and a multiplicity of research projects in related social fields have both provided the foundation for and been derived from space exploration. The University of California's Space Sciences Laboratory has been the location for a good deal of this kind of activity, and its social sciences section, although relatively small, has played a significant role. The experience derived from eight years' functioning of the Social Sciences Group is especially relevant as the Space Sciences Laboratory engages the phase of its activities concerned with satellites and remote sensing technology.

Early in the space program, Mr. James E. Webb, then Administrator of NASA, proposed that a likely and valuable by-product of the massive nationwide endeavor that was to carry men to the moon and vehicles to distant planets might be the sophisticated techniques that had been utilized in the organization and management of this vast and complex

enterprise. His intent, embodied in the 1962 Memorandum of Understanding between NASA and the University of California, was for the university-based program to seek ways in which the benefits of space-derived and related research could be applied to the social, business, and economic structure of the United States. Explicit in this document was the mandate that the environment in which space research was to be conducted would be "characterized by a multi-disciplinary effort drawing upon creative minds from various branches of the sciences, technology, commerce, and the arts." Unlike the product-delivering contracts generally allocated by NASA, this agreement encouraged research and inquiry, placed a premium on a coordination of disciplines, and sought ways in which the talents and technology that had developed for space exploration could be put to socially meaningful use.

The intellectual architects of the Space Sciences Laboratory at Berkeley recognized here a unique opportunity. A program of research with an integrative rather than fragmented thrust seemed all the more desirable because the pursuit of knowledge was taking scholars more deeply into specialized channels; barriers to communication even within disciplines were becoming so marked as to suggest a revival of the allegorical elephant. And this "gulf of incomprehension"\* was widening at the very time when the problems of a technological society

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\*C. P. Snow, The Two Cultures and the Scientific Revolution, New York, Cambridge University Press, 1963, p. 2.

were increasingly more inter-related and interwoven. In seeking a way to maximize the social benefits of technological advance and minimize the social costs, NASA was moving in the direction of the kind of technology assessment about which other government agencies had made much but done little.

While not a perfect antithesis nor even a potent force in counteracting the strong and long term trend toward specialization, establishment of the Space Sciences Laboratory with social science research as an intrinsic function represented a significant effort, worthwhile in its outcome. Especially noteworthy is the fact that the U.S. space endeavor, generally conceived as far out and far removed from human concerns, should have been the vehicle for such down-to-earth preoccupation as exploration of the interface between science and society. The Space Sciences Laboratory provided an environment hospitable to this kind of research orientation because of the concern of its first director, Professor Samuel Silver, for the social implications of technological advance in general and the space program in particular. His sustained interest in the Social Sciences Group supplied a valued linkage where there might otherwise have been only physical contiguity. While no on-location interdisciplinary research emerged from the association, for reasons which will become evident later in this account, members of the Group found the relationship beneficial when they sought access for the conduct of their studies to such places as the Radiation Laboratory on the Berkeley campus and Jet Propulsion Laboratory at Pasadena.

The Group and Seminar functioned under the continued direction and guidance of Professor C. West Churchman, Associate Director of the Space Sciences Laboratory at its founding. Professor Churchman, a management scientist and philosopher, conceived of the Group as a kind of inquiring system and, consistent with Immanuel Kant's view of inquiring systems that they approach the world through a broad mode of representing reality, attracted and encouraged the participation of a spectrum of academic disciplines. At various times, there were graduate students, professional research staff, and professors on this and other campuses in the United States and abroad from a diversity of fields that included economics, management sciences, law, philosophy, sociology, psychology, urban planning, and public administration. The research projects were disparate, that is, not conducted as "team" efforts or centrally coordinated. They were, with a few exceptions in which several members worked jointly, designed and carried out by individual investigators sometimes assisted by a graduate student. There was, however, a cohesiveness of purpose, more evident, perhaps, in retrospective review than during the active years. The total experience as now seen transcends personalities and personal achievements, however significant, and provides interesting perspectives on the pursuit of interdisciplinary research.

The weekly seminar played an important part in the history of the Social Sciences Group. Primarily a forum for the presentation and discussion by members of their research hypotheses, designs, methods, and findings, the meetings attracted considerable participation from visiting scholars and specialists with related interests from government and business. Their range of topics was extensive and the seminars reflected the multiplicity of the members.

Ideally, perhaps, there should have emerged from the interaction a kind of synergism, the phenomenon that is supposed to occur when differences, confronted and reconciled, give way to new approaches. The fact that nothing of the sort took place is a matter which will be scrutinized in the context of the Group's experience, for it is here that some of the basic problems become evident. It might be noted at this point that the lack of a fairy tale ending, in which they all lived together happily forever after, does not imply that this particular interdisciplinary effort failed nor that others are doomed to failure. Quite the contrary. This was a beginning and a useful one. Despite the Group's changing composition and focus, the association of its members having been more or less transient, the Social Sciences Group gradually developed an orientation that, while not characteristic of all of the participants all of the time, nonetheless could be considered its own Weltanschauung, the lasting influence of which can be discerned in many of the subsequent research



pursuits and writings.

The purpose of this account is not to describe in detail the projects nor to attempt to summarize the findings. Such capsule views as would be possible could not do justice to the work of many persons over a considerable period of time. Our intent is to distill from the total experience the lessons and insights which, although unique at the time, may have bearing on forthcoming developments. To achieve this objective, we have grouped the projects into the natural families to which, sometimes, unanticipatedly, they reveal themselves to belong. Our discussion, then, will follow this outline:

- I. Science Policy Decision Making in a Democracy

- A. Areas of Inquiry

1. Philosophy of science
    2. Social roots of quantum physics
    3. Ideology of scientists
    4. Politics of science
      - a. Role of Science Advisory Councils

b. Space politics and policies

1.) Assessment of public attitudes toward space exploration, national and international.

2.) The experimentation with the dialectic

Ethical considerations - the trickster, the expert, and the advocate

5. Can we control technology? - through legislation? social pressure?

II. The Penthouse Experiments - Unanticipated Consequences and Ethical Considerations.

A. Nutritional aspects and their dehumanizing effects.

B. Legal structure of the micro-society.

1. Responses to extreme regulation.

a. Comparison with and implications for other forms of regulated living.

1.) Sea Lab.

2.) Space capsule.

b. How groups learn to live with themselves.

C. Analysis of social and human aspects.

1. Effects of interpersonal relations.

2. Effects on personality structure.

D. Ethics of experimentation with human subjects.

1. Problems of the "hidden agenda."

2. Role of "specialists" or "experts" and concomitant trained incapacity.

3. Deception in social research - intentional and unintentional.

3

4. Means and ends.

- a. Purity of objectives as against tainted means.
- b. "Scientific sacrosanctity" as rationale for research purposes.
- c. Mission - directed vs. open-ended inquiry.

5. Who shall be the judge of morality?

- a. Can social scientists be expected to act more ethically than engineers, physical scientists?
- b. Should social scientists be the gate keepers of the social good?

E. Methodology

- 1. How do we know what we know? - logs, observations, and tests reviewed.

III. The Design of Inquiring Systems.

- A. Information systems as interdisciplinary effort - representing conjuncture of engineering technology, management science, and the social sciences.
- B. SASIDS - an attempt to establish communication among scientists.
  - 1. Obstacles to achieving fidelity of input.
  - 2. Difficulties in sustaining cooperation of participants.
    - a. Pertinence of findings to development of legal and medical information systems.
- C. Information systems as purposive inquiry.
  - 1. Police information networks.
  - 2. Data base for social intervention strategy - in health, education, welfare, etc.
- D. Information systems and the crises of credibility.
  - 1. AEC and the environmentalists.

2. Bureau of Labor statistics and "favorable" reports.
  3. DOD and the state of war and peace.
  - E. Information as power.
    1. Economic
    2. Political
    3. Social
  - F. Methodology and logistics of the information system design.
    1. Comprehensiveness, the model reviewed.
    2. Basis for selection of input.
    3. Time factors.
    4. Consistency of input.
    5. Compatability of categories and items.
  - G. Ethics of information systems.
    1. Neutrality of information.
    2. The dossier.
    3. Data-gathering sources.
  - H. Decisions and data.
    1. Information on a global scale.
      - a. ERTS as data-source.
        - 1.) Who will have access to information?  
How will it be used?
  - I. The decision-making process and information.
    1. The role of information in public administration.
- IV. The Systems Approach.
- A. Philosophy and history.

- B. The systems approach as special case on inquiring system.
  - 1. The Weltanschauung of the analyst.
  - 2. The role of the "expert."
- C. Methodologies reviewed.
  - 1. Simulations and models.
- D. The California experiments with the systems approach.
  - 1. Crime.
  - 2. Transportation.
  - 3. Information.
  - 4. Waste management.
- E. PPBS as a management tool in government.
  - 1. Cost/benefit considered - in recreation and land use, crime, welfare, education, etc.
- F. Systems analysis as outlet for diversification of aerospace talent.
- V. Technologies for Study of the Future.
  - A. "Social indicators," "national goals" and other future-oriented systems analyses.
    - 1. The role of experts.
    - 2. Ethical considerations.
    - 3. The Oedipus theorem and self-fulfilling prophecy.
    - 4. Weltanschauung of the planner.
    - 5. Projections, crystal balls, and other cults.
    - 6. Methodology for devising alternative futures.

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## CHAPTER 3

### USER REQUIREMENTS FOR THE APPLICATION OF REMOTE SENSING IN THE PLANNING & MANAGEMENT OF WATER RESOURCE SYSTEMS

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#### 3.1 INTRODUCTION

The literature abounds with statements of potential applications of remote sensing techniques for obtaining data about earth resources. However, very few attempts have been made to analyze present methods of obtaining earth resource data, to consider the parameters that users of data need, and then to consider the relative merits of acquiring such data by remote sensing techniques.

The research results reported in this chapter analyze hydrologic and water resource systems; establish the major parameters needed to meet the informational requirements of water resource managers; specify when and where data are needed; and suggest the relative merits of classic techniques vs. remote sensing techniques for acquisition of the necessary data. It is recognized that data acquisition and interpretation methods are in a state of continuous improvement which constantly alters the relative merits of a particular technique; however, basic parameters for research and applied water resource management needs should remain relatively constant.

### 3.2 WORK PERFORMED DURING PERIOD COVERED BY THIS REPORT

The fundamental framework within which the analysis was made is a model of the hydrological and water resource systems, and their discrete subsystems, which we have reported upon previously. (Annual Progress Report, May 1971, NASA Grant NGL 05-003-404.) The following subsystems are identified within the model:

- (1) EVAPORATION (EVAPOTRANSPIRATION)
- (2) VEGETATION (Includes soil-vegetation interrelation)
- (3) RAIN & SNOW (PRECIPITATION)
- (4) STREAMS & ESTUARIES
- (5) RESERVOIRS & LAKES
- (6) UNSATURATED SOIL ZONE
- (7) SATURATED ZONE

Although the analysis of each subsystem is reported separately, it is recognized that considerable dependence exists between parameters within the discrete models.

#### 3.2.1 Evaporation Subsystem

The atmosphere serves as a tremendous source or sink for water within the hydrologic cycle and for energy exchange near the earth's surface.

Water remains in the atmosphere above the earth's surface as vapor or precipitates out as rain, hail, or snow. The classic or traditional methods of measuring precipitation are well known and need no elaboration. Water vapor in the atmosphere will be considered in greater detail under evaporation.

Although the sun is the primary energy source, interaction of solar energy with the atmosphere and earth surface results in several identifiable energy components. Emission of energy in the form of electromagnetic waves is referred to as radiation. Energy balance at the earth's surface has two broadly defined radiation components,

solar (short-wave) radiation, and thermal or terrestrial (long-wave) radiation. The total energy spectrum of interest here is the electromagnetic spectrum.

The solar and terrestrial radiation is important in hydrology and water resource management because it is the source of energy to regulate phase changes in water, to provide energy necessary for photosynthesis, and to influence mass transfer within the hydrologic cycle. The classical or traditional method of obtaining radiation data employs a radiometer that is filtered to be sensitive to radiation in the wavelength region of interest. The resulting measurement is a point estimate of radiation that may be instantaneous or time averaged.

The process of evapotranspiration includes the loss of water from a vegetated surface through evaporation from the soil surface and through evaporation from the plant surface (transpiration). Classic or traditional methods of determining evaporation or evapotranspiration rates generally fall into two technique classes, (a) direct measurement using some weighing device (lysimeter), or (b) calculation of rates using parameters known to influence evaporation, such as, water vapor gradient, temperature gradient, wind, radiation, etc. Some of the commonly used methods are: (1) weighing lysimeter which gives a direct measure of evaporation or evapotranspiration over periods as short as a few minutes, (2) evaporation pan which gives a direct measurement of evaporation of water from a specially designed tank, and (3) empirical equations which have been



developed for estimating evapotranspiration using one or more of the meteorological parameters known to influence evaporation rate. Pan evaporation has been used to estimate evapotranspiration for daily rates using a pan coefficient obtained from lysimeter values from the same region (Pruitt, 1960).

One of the commonly used empirical equations is the Jensen-Haise equation (Jensen, 1966) given as  $ET_p = (0.025T + 0.08)R_s$  where  $ET_p$  = predicted potential evapotranspiration rate,  $T$  = temperature in centigrade degrees, and  $R_s$  = solar radiation given as equivalent depth of evaporation.

Perhaps the most frequently used research method of estimating evapotranspiration is the energy balance method. The energy balance equation as given by Tanner (1960) is:

$$LE = \frac{-(R_n + G)}{1 + \gamma (\Delta T / \Delta e)}$$

where  $L$  = latent heat of vaporization

$E$  = evaporation rate

$R_n$  = net radiation flux

$G$  = soil heat flux

$T$  = temperature gradient

$e$  = vapor pressure gradient

$\gamma$  = psychrometric constant

All of the methods of measuring or calculating evapotranspiration rates have limitations and undesirable features. Lysimeters are

expensive and hydrologically dissimilar to the field. Since evapotranspiration rates are not always a function of the energy supply, equations based on meteorological parameters are not always correct. The principal parameters and user requirements in the evaporation subsystem are tabulated in Table 3.1. The methodology suggested herein for utilizing remote sensing technology in the determination of evapotranspiration (ET) rates relates the potential for measurement of surface temperature, solar radiation, atmospheric water vapor and other parameters, to rigorous mathematical and empirical equations described herein for indirectly deducing ET. Certainly vegetative cover (i.e., its composition and density as measured by remote sensors) can give a reasonable estimate of potential ET with an accuracy suitable for many watershed management and water resource planning purposes. Phase III of the proposed research will test user applications in operating systems.

### 3.2.2 Vegetative Subsystem

The vegetative subsystem plays several concurrent roles in the hydrologic cycle which are identified in Figures 3.3, 3.4, 3.5, and 3.7 of the Annual Progress Report of May 1, 1971 (NASA Grant - NGL 05-003-404). It is implied but not specifically identified in the stream and lake subsystems that nonvascular aquatic plants are indirectly related to the hydrologic cycle. Aquatic plants are given special treatment in Tables 3.3 and 3.4.

The planning of water resource developments and the management of water resource systems requires an understanding and a quantitative

TABLE 3-1. THE EVAPORATION SUBSYSTEM

HYDROLOGIC PARAMETER and APPLICATION	M E A S U R E M E N T			STANDARD USER REQUIREMENTS		REMOTE SENSING DATA ACQUISITION	
	a. Parameter	a. Frequency	a. Ground Resolution	User Techniques	Standard Data Acquisition Methods	Parameter Sensed, and Instrumentation	Priority Region of E-M spectrum
EVAPORATION from free water surfaces (eg. lakes) for water resources planning & operations	a. flux	a. daily	a. 1 km	1. direct measurement	evaporation pan	1. surface temperature - thermal IR scanner	3-5µm, 8-14µm
	b. 1-6 cm/wk	b. average	b. ± 10 km <sup>2</sup>	2. estimate (no seepage)	water level indicator	2. reflectance - multi- spectral scanner	0.2 - 14µm
	c. ± 0.25 cm/wk			3. prediction equation	Eq. Penman equation $E_o = \frac{m H + 0.27 E_a}{m + 0.27}$		
EVAPORATION from free water surfaces for hydrologic research on the evaporation process	a. flux	a. continuous or hourly	a. 0.4 km	1. direct measurement	recording evaporimeter	1. surface temp. - thermal IR scanner	3-5µm, 8-14µm
	b. 0-1 cm/day	b. hour avg.	b. ± 0.4 hectare	2. direct measurement measured	recording evaporation pan	2. temperature & water vapor profiles - infrared spec- trometer	5 - 20µm
	c. ± 0.05 cm/day			3. water vapor profiles	infrared spectrometer	3. reflectance surf. - multi- spectral scanner	0.2 - 14µm
EVAPOTRANSPIRATION evaporation from a vegetated surface for water resources planning & operations	a. flux	a. daily	a. 1 km	1. direct measurement	non-weighing lysimeter	1. surface temp. - thermal IR scanner	3-5µm, 8-14µm
	b. 1-5 cm/wk	b. average	b. ± 10 km <sup>2</sup>	2. estimate with coef- ficient	evaporation pan	2. reflectance - multi- spectral scanner	0.2 - 14µm
	c. ± 0.25 cm/wk			3. calculate using meteorological data	Eg. Jensen-Haise equa- tion $ET = (aT + b)R_s$	3. water content - micro- wave radiometer	10 - 40 GHz
EVAPOTRANSPIRATION evaporation from a vegetated surface for hydrologic research on evapotranspiration processes	a. flux	a. continuous or hourly	a. 0.4 km	1. direct measurement	accurate weighing ly- simeter	1. temp. & water vapor pro- file - grd. data collec- tion platform (Bowen Instruments)	5 - 20µm
	b. 0-1 cm/day	b. hour avg.	b. ± 0.4 hectare	2. derive by energy budget analysis	Eg. Tanner equation $R_n - S$ $LE = \frac{R_n - S}{1 + \beta}$	2. Temp. & water vapor pro- file - infrared spectrome- ter	
	c. ± 0.05 cm/day			3. prediction equations	Eg. $E = f(u)(e_o - e_a)$	3. water content - microwave radiometer	10 - 40 GHz
VEGETATION WATER STRESS as an indicator of soil water and meteorological conditions	a. water potential	a. daily during drought season	a. 100 m	1. ground reconnaissance	visual examination	1. reflectance - multi- spectral photography	0.3 - 3.0µm
	b. 0 - 20 bars	b. average	b. ± 10 hectares	2. water potential	visual reading of water potential sen- sors	2. surface temp. - thermal scanner	3-5µm & 8-14µm
	c. ± 0.5 bar			3. water content	field measurement of water cont. & relate to tension curve		

TABLE 3-1. (CONT'D.)

<b>RADIATION</b> incoming solar radiation as weather data for estimating ET and energy available	a. flux b. 200-700 ly/day c. $\pm 50$ ly/day	a. daily b. average (daytime only)	a. 10 km b. $\pm 100$ km <sup>2</sup>	1. direct measurement 2. direct measurement 3. estimate from weather data	Eppey-type radiometer integrating radiometer radiometer or sunshine recorder	1. reflectance - multi- spectral scanner 2. radiance - infrared imager & cloud co- efficient	0.3 - 4.0 $\mu$ m 8 - 14 $\mu$ m
<b>RADIATION</b> solar and net radiation for energy balance and photo- synthesis research	a. flux b. 0-2 ly/min c. $\pm 0.1$ ly/min	a. continuous or 10-min b. 10 min avg.	a. 0.1 km b. $\pm 1$ km <sup>2</sup>	1. direct measurement 2. est. photosynthesis radiation	recording radiometer filtered recording radiometer	1. reflectance solar data collection - multispectral scanner 2. solar radiation - data collection platform & recording radiometer 3. polarization - polarizer	0.3 - 4.0 $\mu$ m
<b>TEMPERATURE</b> basic weather data for hydrologic planning & thermal energy related operations	a. temperature b. -40 to +60 °C c. $\pm 1$ °C	a. hourly or 4-hr b. average	a. 10 km b. $\pm 100$ km <sup>2</sup>	1. contact measurement 2. non-contact measure- ment	Thermometer, thermis- tor or thermocouple long-wave pyranometer	1. temperature - thermal scanner 2. radiance - multispectral imagery with special data system	3 - 20 $\mu$ m 0.3 - 1.1 $\mu$ m
<b>TEMPERATURE</b> temp. profiles and surface temperature for thermal exchange research	a. temperature b. 0-50 °C c. $\pm 0.5$ °C	a. continuous b. instantaneous	a. 0.1 km b. $\pm 1$ km <sup>2</sup>	1. contact measurement 2. contact measurement 3. non-contact measurement 4. non-contact measurement	thermistors or thermo- couple resistance thermometer infrared thermometer radiosonde	1. surface temp. - infrared thermometer 2. temp. profiles - IR inter- ferometer spectrometer 3. surface temp-thermal scanner	3 - 20 $\mu$ m 6 - 6.5 $\mu$ m 3-5 $\mu$ m, 8 - 14 $\mu$ m
<b>WATER VAPOR</b> atmospheric profiles for water transfer research involving the hydrologic cycle	a. relative humidity profiles b. 10-90% rh c. $\pm 2\%$ rh	a. continuous or 30-min b. Point estimates	a. 1 km b. $\pm 10$ km <sup>2</sup>	1. direct measurement 2. direct measurement	radiosonde humidity sensors	1. water vapor - radiosonde 2. Infrared - interferometer spectrometer	6 - 6.5 $\mu$ m
<b>WIND</b> weather data and wind function data for prediction equations	a. speed & direction b. 0-80 km/hr; 0-360° c. $\pm 10\%$	a. daily or hourly b. point estimates	a. 1 km b. NA	1. direct measurement 2. indirect measurement	cup anemometer sonic anemometer	1. speed or direction - data collection platform & instruments 2. Speed - sonic anemometer 3. Wave analysis on water	0.7 - 3.0 $\mu$ m 0.3 - 1.1 $\mu$ m
<b>VEGETATION COVER</b> as an indicator of evapotranspiration potential	a. % cover b. 0 - 100% c. $\pm 5\%$	a. Once per month b. Average	a. 100 m b. $\pm 10$ hectares	1. photo interpretation 2. ground reconnaissance	aerial photographs visual examination	1. reflectance - infrared photography 2. reflectance - multi- spectral photography (with image enhancement)	0.7 - 3.0 $\mu$ m 0.3 - 1.1 $\mu$ m

evaluation of the influence of watershed vegetation on the basic hydrologic cycle. For example, Burgy's studies on the Hopland and Placer Experimental watersheds and on the Upper Putah Creek watershed have directly involved the quantification of runoff increments from vegetation manipulation (Burgy, 1970). There is considerable promise for the use of remote sensing techniques in the monitoring of soil instability, erosion, and land slumps resulting from natural vegetative successions, and recording man-induced changes from logging and brush conversion. The report subsections following relate both lake and stream-estuary subsystems to the possible user application of remote sensing in assessing sediment transport and deposition phenomena.

### 3.2.3 Rain and Snow Subsystem

Utilizing the principle of radar signal attenuation by rainfall, Russian investigators Volynets et al have found good correlation between rain-gauge measurements and estimates based on radar attenuation-rainfall relationships (Volynets et al, 1965). The use of an active sensor is almost mandatory for measuring precipitation rates occurring as rainfall. Most reflective bands of the E-M spectrum except in the microwave and thermal IR range are fully attenuated under meteorologic conditions which would be associated with measurable precipitation. For example, Moore et al reported on the work of Medhorst who found that radar is truly an all-weather sensor and that systems operating at wave-lengths beyond 10 cm are essentially unaffected by any meteorological condition (Moore et al,

1967). It should be obvious that in many user applications in water resource management such as flood forecasting and weather modification research, an all weather sensor would be indispensable. The monthly synoptic photographic coverage, scale 1:100,000, obtained by NASA during the winter of 1970-71 of the snow pack at the Bucks Lake test site when interpreted by personnel of the Forestry Remote Sensing Laboratory showed a high correlation between such data and actual stream discharge and snow survey measurements. Hence that work has revealed the potential of remote sensing in the monitoring of snow for watershed yield predictions and spring snowmelt flood potential forecasting. Unlike rainfall, the rate of snowfall is less important than the characterization of the aerial extent and water content of the accumulated snow.

Table 3.2 lists the user needs and data requirements for both the vegetative, and the snow and rain (i.e., precipitation) subsystems.

#### 3.2.4 Stream and Estuary Subsystem

A distinction has been made in this report between the user requirements for streams and for estuaries, even though the subsystem parameters are identical with the exception of flow reversal possibilities in estuaries.

Both streams and estuaries are hydrodynamic systems whereas lakes and reservoirs are virtually static except for internal circulation. Volume-storage characteristics are of importance in lakes and reservoirs while rates of flow are important in stream systems.

TABLE 3-2. THE VEGETATION AND PRECIPITATION SUBSYSTEMS

HYDROLOGIC PARAMETER and APPLICATION	M E A S U R E M E N T			STANDARD USER REQUIREMENTS		REMOTE SENSING DATA ACQUISITION	
	a. Parameter	a. Frequency	a. Ground Resolution	User Techniques	Standard Data Acquisition Methods	Parameter Sensed and Instrumentation	Priority Region of E M Spectrum
SOIL WATER CONDUCTIVITY for water flow characteristics of soil in hydrologic analyses	a. Parameter	a. One time at several water contents	a. 100 m or soil boundaries	1. lab water outflow	visual reading of volume outflow	1. water potential - data collection platform and water potential instru- ments	
	b. Est. Range	b. Point Est. or Avg.	b. Area Tolerances	2. field water potential	visual reading of tensiometers	2. water content, data collection platform and water content sensors	
	c. Desired Accuracy	b. Point estimate	given soil area				
SOIL WATER CONTENT for water storage estimates, flood fore- casting, and ante- cedent watershed conditions	a. % by volume	a. daily	a. 100 m	1. gravimetric	weighing and oven drying of soil samples	1. water content data, data collection plat- form and water sensors	
	b. 5% - 60%	b. average	b. $\pm$ hectares	2. neutron scattering	visual reading of scaler counter used with neutron probe	2. surface temperature - thermal scanner	3-5 $\mu$ m & 8-14 $\mu$ m
	c. $\pm$ 2%					3. microwave - radiometer	10-35 GHz
SOIL WATER INFILTRATION for deducting runoff estimates in water resources planning and operations	a. flux	a. Once for a given soil over a range of water contents as a function of time	a. 1 km or soil boundaries b. $\pm$ 1 km <sup>2</sup> or given soil area	1. lab infiltrometer	visual reading of water volume flow through soil cores	1. reflectance - multi- spectral photography (with image enhance- ment)	0.4-1.1 $\mu$ m
	b. < 0.1 ->	b. Average		2. field ring infiltrom- eter	visual reading of inflow depth	2. land forms - radar and soils (side looking)	1.5-100 cm
	c. $\pm$ 0.05 cm/hr			3. field sprinkling infiltrometer	record application & runoff rates		
SOIL TYPE as an Indicator of physical and chemical proper- ties of the soil and assoc. land forms affecting hydrology	a. soil system	a. once	a. boundaries within a few meters	1. soil survey and classification	visual & physical exam of soil profiles & land forms	1. reflectance - multi- spectral photography	0.4-1.1 $\mu$ m
	b. variable	b. average	b. $\pm$ 20 hectares	2. photo interpretation with ground truth	aerial photographs and ground reconnaissance	2. land forms - side looking radar	1.5-100 cm
	c. $\pm$ 10% error					3. microwave - radiometer	1.5-35 GHz
VEGETATION TYPE as an indicator of pre- cipitation intercept- ion, runoff & water extraction potential	a. plant species and density	a. once per month	a. boundaries within a few meters	1. ground reconnaissance and survey	visual examination and mapping	1. reflectance - infrared photography	0.7-3.0 $\mu$ m
	b. variable	b. average	b. $\pm$ 10 hectares	2. photo interpretation	aerial photographs	2. reflectance - multi- spectral photography (with image enhance- ment)	0.3-1.1 $\mu$ m
	c. $\pm$ 10% error						
PRECIPITATION rain or snow as weather data for water resources planning and operations	a. depth (snow--water equivalent)	a. daily	a. 1 km	1. direct measurement	rain gauge	1. rainfall - ground data collection platform and instruments	
	b. 0-15 cm/day	b. average	b. $\pm$ 10 km <sup>2</sup>	2. snow depth & water content	sample tube--water equiv.	2. rainfall distribution - radar	
	c. $\pm$ 0.2 cm/day			3. areal extent (snowpack)	snow survey	3. reflectance - multi- spectral scanner	0.2-14 $\mu$ m
PRECIPITATION rainfall or snowfall for hydrologic research on runoff and flood prediction	a. flux	a. continuous or 30-min cum.	a. 1 km	1. direct measurement	recording rain gauge	1. a. rainfall rate - data collection platform and recording gauge	
	b. 0-10 cm/hr	b. 30 min avg.	b. $\pm$ km <sup>2</sup>	2. snow depth	snow recorder	b. radar -	1.0-4 cm
	c. $\pm$ 0.1 cm/hr					2. reflectance for distri- bution - multispectral scanner and special data system	0.2-14 $\mu$ m
WATER VAPOR precipitable water in the atmosphere for water resource planning and operations	a. mixing ratio	a. hourly or 4-hour	a. 10 km	1. direct measurement	radiosonde	1. infrared - interferom- eter spectrometer	6-6.5 $\mu$ m
	b. 0.01-20 g/kg	b. average	b. $\pm$ 100 km <sup>2</sup>	2. direct measurement	humidity sensors	2. water vapor - radiosonde	
	c. $\pm$ 0.2 g/kg						

Concurrent work of the UCLA investigative team of Shubert and Lingenfelter relates stream morphology, as revealed by meander patterns, to some value of stream discharge or average precipitation over a tributary drainage area. The statistical analyses necessary to correlate channel changes with river hydraulics are not yet completed but offer a user possibility not considered in Table 3.3. It is important to recognize that the work of Shubert et al could be of inestimable value in water resources planning, yet the need for instantaneous characterization of stream hydraulics cannot be obviated as the criteria for more responsive and sophisticated methods of operation for water resource systems evolve.

Concurrent interest by industry and water quality enforcement entities in the detection and surveillance of oil films on inland and coastal water masses, requires that special attention be given to this pollutant, which shows promise of detection at concentrations as low as 0.007 mg/l using remote sensors (Mattson, 1971; Edgerton et al, 1969; Hom, 1968). Table 3.3 suggests the application of remote sensing technology to the measurement of stream and estuarine hydrologic and hydraulic phenomena.

#### 3.2.5 Lake and Reservoir Subsystem

Special interest in the management of lakes and other impoundments in recent years has centered on the process of eutrophication, or aging. The phenomenon is closely linked to the limiting growth factors for the lakes primary producers, algae. The most common criterion for judging the eutrophic potential of a lake is the abundance of the



TABLE 3-3. THE STREAM AND ESTUARY SUBSYSTEM

HYDROLOGIC PARAMETER and APPLICATION	M E A S U R E M E N T			STANDARD USER REQUIREMENTS		REMOTE SENSING DATA ACQUISITION	
	a. Parameter	a. Frequency	a. Ground Resolution	User Techniques	Standard Data Acquisition Methods	Parameter Sensed and Instrumentation	Priority Region on E M Spectrum
OIL & OTHER HYDRO- CARBON SURF. FILMS for water quality control	a. concentration & distribution	a. as required	a. 30 m.	1. surface surveillance	1. sampling and analysis	hydrocarbon surface film - 1. microwave radiometer	8.5 $\mu$ - 12.5 $\mu$ or 13.5-19 $\mu$ m
	b. 0.007 - 50 mg/l	b. average	b. $\pm$ 0.1 ha.	2. aerial surveillance	2. BW/color photo- graphy (distribution only)	2. UV imager	2900-4000 Å
	c. $\pm$ 5%						
SURFACE VELOCITY & DIRECTION for hydraulic characteri- zation	a. velocity	a. as required	a. 10-30m	1. field measurement	1. current meter	wave form - 1. T-11 camera	0.5-0.7 $\mu$ BW
	b. 0.1-6 m/sec	b. average	b. $\pm$ 0.1 ha.		2. slope area		
	c. $\pm$ 0.5 m/sec						
STREAM MORPHOLOGY for geophysical characterization	a. physical change	a. 1-5 yr.	a. 10-30m	1. field surveys	1. transit/tape traverse	meander, slope, depth - 1. T-11 camera	0.5-0.7 $\mu$ BW
	b. ---	b. average	b. $\pm$ 0.1 ha.				
	c. ---						
SUSPENDED SEDIMENT for sediment protec- tion and deposition studies (concentra- tion gradient)	a. suspended solids	a. as required	a. 30m	1. field sampling and lab analysis	1. gravimetric analysis	suspended sediment plume	0.5-0.7 $\mu$ BW and color
	b. 0-5000 mg/l	b. average	b. 0.5 ha.			1. T-11 camera	
	c. $\pm$ 10%					2. multispectral scanner	0.9 $\mu$ 0.3-0.4 $\mu$ near UV
WATER CHEMISTRY for water quality management (total dissolved solids)	a. total dissolved solids	a. as required	a. NA	1. <u>in situ</u> measurement	1. elec-chem probe	total dissolved solids (salinity)	7.5 cm $\mu$
	b. 100-35,000 mg/l	b. average	b. NA	2. field sampling and lab analysis	2. Wheatstone bridge or gravimetric	1. microwave imager	
	c. $\pm$ 10%						
SURFACE TEMP. & TEMP. ANOMALIES for water quality management	a. temperature	a. as required	a. NA	1. thermograph	1. <u>in situ</u> direct measurement	surface temperatures - IR radiometer	8-14 $\mu$ Thermal IR
	b. 4-20°C	b. point estimates	b. NA				
	c. $\pm$ 1°K						
PHYTOPLANKTON DENSITY for eutrophication rate determinations	a. cells/unit volume	a. as required	a. 10-30m	1. sampling and lab analysis	1. cell counts per unit volume	phytoplankton chlorophyll - - RC8 camera - UV detector - T-11 camera	0.7-0.9 $\mu$ Color IR 0.3-0.4 $\mu$ UV (near) 0.5-0.7 $\mu$ Color
	b. 10-50 cells/ml	b. average	b. $\pm$ 0.1 ha.				
	c. $\pm$ 10%						
EMERGENT AQUATIC PLANTS for water quality management	a. density & species	a. annually	a. 50m	1. shoreline survey	1. biological inventory	macrophyte chlorophyll - -RC8 camera -UV detector -T-11 camera	0.7-0.9 $\mu$ Color IR 0.3-0.4 $\mu$ UV (near) 0.5-0.7 $\mu$ Color
	b. 10-100m <sup>2</sup>	b. average	b. $\pm$ 50m <sup>2</sup>				
	c. $\pm$ 50m <sup>2</sup>						
SURFACE DISSOLVED OXYGEN for rate of regeneration	a. dissolved oxygen	a. seasonally, as required	a. NA	1. <u>in situ</u> measurement	1. dissolved oxygen - electro-chem. probe	dissolved oxygen - correlate to saturation DO for particular surf. temp. & barometric press. wind vel. & wave pattern	8-14 $\mu$ Thermal IR 13.5-19 mm Passive microwave
	b. 5-10 mg/l	b. point estimate	b. NA	2. sampling and lab analysis	2. winkler determina- tions		
	c. $\pm$ 1 mg/l						
FINFISH LOCATIONS & POPULATIONS for Finfish management	a. number & location	a. seasonally, as required	a. 30 m	1. <u>in situ</u> fish counts	1. numerical counter	fish - UV detector Gamma radiometer	0.3-0.4 $\mu$ UV (near)
	b. 50-5000 orgs.	b. point estimates	b. $\pm$ 0.1 ha.				
	c. $\pm$ 20%						
STREAM STAGE AND/OR DISCHARGE for flood forecasting & channel storage	a. discharge	a. continuous	a. NA	1. <u>in situ</u> measurement	1. stage-discharge recorder	discharge - --- (see velocity)	---
	b. 100-10,000 m <sup>3</sup> /sec	b. average	b. NA				
	c. $\pm$ 10%						
MAPPING ICE - WATER BOUNDARIES for tim- nological research in inclement weather	a. type & quantity of ice	a. as required, seasonally	a. 30m	1. field surveys and observations	1. field survey teams	ice - passive microwave	13.5-19 mm Passive microwave
	b. ---	b. average	b. $\pm$ 0.1 ha.				
	c. ---						

macronutrients, nitrogen (N), and phosphorus (P).

The possibilities of determining concentrations of N and P successfully using remote sensing techniques appear slight; however, the monitoring of the mixed standing crop of algae is feasible, particularly if advantage be taken of the possibilities of obtaining special signatures from particular algal species having different biochromes in their cell ultrastructure. These possibilities will be explored by the Davis group working closely with other members of the integrated research team in the delta and coastal estuarine elements of the study.

The studies of Silvestro (1970) and Clarke et al (1969) have shown that state of the art instrumentation and interpretation can be used to quantify suspended materials in water. Silvestro found the spectral region 0.6 to 0.7 particularly sensitive to changes in suspended material concentrations (Ibid, 1970).

The ability to study the heat and energy balance of a lake system may be greatly simplified by the use of remote sensors. Thermal enrichment and diffusion of heat energy within a water body from input sources can be mapped seasonally to reflect internal circulation of an impoundment and the attendant redistribution of heat.

The oxygen resources of a lake system are also of prime importance in the management of the biota of the system and in protecting the uses of water which require potability and general good appearance, as for example to a recreationist. Measurement of dissolved oxygen concentration directly, however, does not appear feasible with the

present state of the art. Possibilities for estimating the saturation concentration for the surface water zone by deducing values using a dissolved oxygen model and other measurable parameters such as temperature, reaeration constant from wind and wave analyses, and vapor pressure need further study.

The measurement of subsurface phenomena and parameters will depend to a great degree on the technological advances made in active sensors which can penetrate water or other materials, and in a more enlightened understanding of passive microwave emittance in the aquatic environment.

Table 3.4 lists lake subsystem parameters and user requirements for which remote sensing appears feasible.

#### 3.2.6 Unsaturated Soil Subsystem

The application of remote sensors to an understanding of the unsaturated soil subsystem is more severely restricted due to the greater percentage of occurrence of phenomena and processes taking place underground beyond the effective region of presently used portions of the electromagnetic spectrum.

Some possibilities exist for deducing subsurface soil and soil moisture conditions from the behavior of overlying vegetation. The problem of quantifying data from such interpretations may be limiting. Soil surface moisture content has good potential for measurement with remote sensors and could be extrapolated to depth if sufficient ground truth were known concerning free draining characteristics of the soil, subsurface geology (e.g., the presence of impermeable layers) and

TABLE 3-4. THE RESERVOIR AND LAKE SUBSYSTEM

HYDROLOGIC PARAMETER and APPLICATION	M E A S U R E M E N T			STANDARD USER REQUIREMENTS		REMOTE SENSING DATA ACQUISITION	
	a. Parameter	a. Frequency	a. Ground Resolution	User Techniques	Standard Data Acquisition Methods	Parameter Sensed and Instrumentation	Priority Region of E-M spectrum
LAKE SURF. AREA For volume - surf. area relationships	a. area	a. as required	a. 100 or $\approx$ 31 m	1. deduce from water level & known lake geometry	1. water level recorder	1. area - 86W photo	visible
	b. 0.1-0.24 ac.	b. average	b. $\pm$ 0.5 ha.	2. Traverse offsets & Simpson's 1/3 Rule	2. fathometer soundings		
LAKE DEPTH For lake geometry & sedimentation rate (gross lake morphology)	a. depth	a. as required	a. NA	1. direct hydrographic measurement	1. fathometer	1. bottom reflect-spec.	0.55-0.58 $\mu$ 0.8-1.0 $\mu$
	b. 0-100 m	b. point est.	b. NA		2. lead line	2. wave analysis-Fourier transf.	0.62-0.66 0.5-0.7 $\mu$ 86W
DEPTH TO THERMOCLINE For limnologic determinations	a. depth °C/m	a. seasonally,	a. NA	1. temperature - depth profile	1. bathythermograph	3. thermal anomalies	-
	b. 0-50 m	b. point estimate	b. NA			4. laser ranging	direct depth meas.
WATER CHEMISTRY STRATIFICATION For redox potential measurements	a. TDS	a. seasonally	a. NA	1. sampling & analysis	1. lab. chem. analysis	1. instrument buoy or/	passive microwave 13.5-19 mm
	b. 50-1000 mg/l	b. point estimate	b. NA	2. 5-channel probe (electrochemical)	2. in-situ field measurement	1. instrument buoy or/	
PHYTOPLANKTON DENSITY For nutrient enrichment determinations & eutrophication studies	a. cells/unit vol.	a. seasonally as required	a. NA	1. sampling & analysis	1. cell counts per unit volume	1. phytoplankton chloro- phyll, IR film	color 0.7-0.9 $\mu$ infrared 0.3-0.4 $\mu$ UV (near) 0.5-0.7 color
	b. 10-50 cells/ml	b. average	b. NA				
EMERGENT AQUATIC PLANTS For eutrophication and lake morphology studies	a. density & species	a. annually	a. 50 m	1. shoreline survey	1. biological inven- tory	1. macrophyte chloro- phyll, IR film	color 0.7-0.9 $\mu$ infrared 0.3-0.4 $\mu$ UV (near) 0.5-0.7 color
	b. 10-100 m <sup>2</sup>	b. average	b. $\pm$ 50 m <sup>2</sup>				
(same as LAKE SURFACE AREA above)							
SURFACE DISSOLVED OXYGEN For rate of respiration	a. dissolved oxygen	a. seasonally as required	a. NA	1. dissolved oxygen probe (electro-chemical)	1. field determinations, direct measurement	1. correlate to satur.	8-14 $\mu$ thermal IR
	b. 5-10 mg/l	b. point estimate	b. NA	2. Winkler determinations	2. sampling & lab. analysis	30 for particular surf. temp. & barometric pressure & wind & wave action	13.5-19 mm micro-wave
SURFACE TEMPERATURE For thermal enrichment studies & heat bal. determinations	a. temperature	a. as required	a. NA	1. thermograph	1. field determination, direct measurement	1. radiometer-tempera- ture	8-14 $\mu$ thermal IR
	b. 4-20°C	b. point estimates	b. NA				
TURBIDITY For water quality control & algal growth potential studies	a. turbidity	a. as required	a. 30 m	1. sampling & lab. analysis	1. Jackson turbidimeter	1. turbidity - multispectral scanner	86W & 0.5-0.7 $\mu$ color 0.9 $\mu$ near IR 0.3-0.4 $\mu$ near UV
	b. 0-10 <sup>4</sup> JNU	b. average	b. $\pm$ 0.5 ha.				
LIGHT TRANSMITTANCE For algal growth potential studies	a. light transmittance	a. as required	a. NA	1. submerged photoelectric cell	1. photo cell	1. light reflectance from backscatter - multispectral	0.55-0.58 $\mu$ 0.8-1.0 $\mu$ 0.62-0.66 $\mu$
	b. 0-1000 ft-candles	b. average	b. NA	2. deduce by susp. solids concentration			
SUSPENDED SOLIDS For concentration gradient determinations & algal growth potential studies	a. suspended solids	a. as required	a. 30 m	1. sampling and lab. analysis	1. field measurement & lab. determination	1. susp. sediment plume	0.5-0.7 $\mu$ visible 86W & color
	b. 0-5000 mg/l	b. average	b. $\pm$ 0.5 ha.				
	c. $\pm$ 10%						

capillary conductivity of the soil. Infiltration rates, as well, can be related to remotely observed surface phenomena although they probably are best measured under an artificially applied precipitation condition which could be correlated to actual rainfall occurrence when meteorological conditions would prevent the sensing of most surface phenomena. Thermal sensing techniques are being explored in current studies by Myers et al and others. Microwave instrumentation is being developed and tested as another remote sensor capability for characterizing some soil properties, although present efforts are confined to lower elevation platforms because of the physical requirements of the apparatus. Again, advancement of active sensor technology previously described suggests future opportunities for measuring infiltration rates under all weather conditions. The parameters and user applications comparing traditional data acquisition and remote sensing possibilities are presented in Table 3.5.

#### 3.2.7 Saturated Subsystem

The saturated subsystem, often described as the zone of groundwater, could occupy all of the unsaturated zone during periods of high water table conditions. Some excellent possibilities exist for the acquisition of certain data relating to the size and indirectly to the overall dimensions of the saturated zone and the location and condition of geologic surface zones of groundwater recharge as well. Likewise, the monitoring and possible quantification of groundwater leakage by identification of leakage zones created by geologic

TABLE 3-5. THE UNSATURATED ZONE SUBSYSTEM

HYDROLOGIC PARAMETER and APPLICATION	M E A S U R E M E N T			STANDARD USER REQUIREMENTS		REMOTE SENSING DATA ACQUISITION	
	a. Parameter	a. Frequency	a. Ground Resolution	User Techniques	Standard Data Acquisition Methods	Parameter Sensed and Instrumentation	Priority Region of E-M Spectrum
DIRECTION OF FLOW for miscible displacement studies and salt transport in soil water	a. direction up or down	a. as required	a. 30 m	1. measure soil moisture tension & apply Darcy's law	1. tensiometers, resistance blocks or neutron probe	-	-
	b. -	b. average	b. $\pm$ 0.5 ha.				
	c. -						
POROSITY for determination of percent voids in soil	a. porosity	a. as required	a. NA	1. undisturbed soil sample, lab analysis	1. laboratory analysis	-	-
	b. 0-30 percent	b. average for soil body	b. NA				
	c. $\pm$ 5 %						
THICKNESS OF UNSAT. ZONE for drainage characterization of soil body & depth to saturated zone in unconfined aquifers	a. meters	a. as required	a. 30 m	1. auger, well log, water level recorder	1. field direct measurement	native vegetation, deep rooted species - rooting depth	-
	b. 0-300 m	b. average over discrete area	b. 0.5 ha.				
	c. $\pm$ 0.5 m						
MOISTURE CONTENT for agri. operations & water res. systems management incl. flood forecasting	a. percent	a. as required	a. 30 m	1. measure soil mois- ture tension & relate to water content analysis	1. tensiometers, re- sistance blocks or neutron probe 2. gravimetric methods	(see vegetative sub-system SOIL WATER CONTENT)	
	b. 0-100	b. average over discrete area	b. 1 ha.				
	c. $\pm$ 5%						
INFILTRATION	(see vegetative system, SOIL WATER INFILTRATION)						
SALINITY OF SATURATED SOIL EXTRACT	a. total dissolved solids	a. as required	a. NA	1. deduce from soil water conductivity	1. Wheatstone Bridge	-	-
	b. 0-5000 mg/l	b. point estimate		2. gravimetric analysis of soil water sample	2. laboratory analysis		
	c. $\pm$ 10%						

discontinuities, or water mass exchanges between adjacent basins manifested in surface evidence of rising water or phreatophyte concentrations may be remotely sensed.

Like the unsaturated zone, monitoring the saturated zone with remote sensors using the present state of the art appears to be limited. Several new techniques of analysis of thermal responses and other energy bands of the spectrum are being refined and may be applicable in the immediate future.

The user applications and traditional hydrologic problems of importance in the saturated zone are outlined in Table 3.6.

#### 3.2.8 Summary

The data developed herein to relate hydrologic system and subsystem models to user applications and remote sensing technology hold promise in the planning and management of water resource systems and in shorter term hydrologic forecasting activities.

Prototype testing of remote sensing user applications suggested will be pursued in the remaining portion of the second phase of the integrated study and developed into operational feasibility within the term of the project.

The results of research reported as progress to date may expand in detail and content by the interchange among members of the integrated research team through reanalysis and interpretation using the feedback mechanisms incorporated in the coordinated work plan.

Willingness of the potential users within the test site to make remote sensing technology work by assisting the research teams in

TABLE 3-6. THE SATURATED ZONE SUBSYSTEM

HYDROLOGIC PARAMETER and APPLICATION	M E A S U R E M E N T			STANDARD USER REQUIREMENTS		REMOTE SENSING DATA ACQUISITION	
	a. Parameter	a. Frequency	a. Ground Resolution	User Techniques	Standard Data Acquisition Methods	Parameter Sensed and Instrumentation	Priority Region of E-M spectrum
	b. Est. Range	b. Point Est. or Avg.	b. Area Tolerances				
	c. Desired Accuracy						
<u>WATER TABLE</u> <u>GRADIENT</u> for groundwater basin outflow determinations (piezometric level)	a. meters b. 0-300 m c. $\pm 0.5$ m	a. as required b. average over discrete area	a. 30 m b. 0.5 ha.	1. auger, well log, water level recorder	1. direct field measurements	native vegetation, deep rooted species - rooting depth	-
<u>AQUIFER</u> <u>DIMENSIONS</u> for safe yield and total groundwater reservoir storage determinations (shape of hypervolume)	a. meters b. varies c. $\pm 100 \text{ m}^3$	a. once as required b. -	a. 30 m b. 0.5 ha.	1. well logs, geologic structure	1. direct field measurements 2. aerial photos of basin surface area	surface area - T-11 camera	0.5-0.7 $\mu$
<u>GROUNDWATER</u> <u>BASIN RECHARGE</u> <u>ZONES</u> for groundwater basin management	a. area b. varies c. $\pm 5$ ha.	a. once as required b. -	a. 100 m b. $\pm 5$ ha.	1. geologic field 2. aerial photo interpretation	1. field measurements 2. photo interpre- tation	1. geol. discont. - T-11 camera	0.5-0.7 $\mu$
<u>COEFFICIENT OF</u> <u>PERMEABILITY</u> for groundwater movement studies	a. $\text{m}^2/\text{day}/\text{m}^2$ b. varies c. $\pm 5\%$	a. as required b. average	a. NA b. NA	1. undisturb. soil sample and analysis	1. laboratory analysis	-	-
<u>GROUNDWATER</u> <u>TEMPERATURE</u> for limits on plant germination	a. $^{\circ}\text{C}$ b. 6-25 $^{\circ}\text{C}$ c. $\pm 1^{\circ}\text{C}$	a. as required b. point estimates	a. NA b. NA	1. thermograph	1. direct measurement	-	-
<u>GROUNDWATER</u> <u>WITHDRAWALS</u> for groundwater basin management	a. $\text{m}^3/\text{month}$ b. varies c. $\pm 20\%$	a. continuous b. average	a. NA b. NA	1. pump operation analysis 2. flow meter each pump, totalized for basin	1. direct measurement	-	-
<u>GROUNDWATER</u> <u>LEAKAGE ZONE</u> for groundwater basin management	a. area b. 1-5 ha. c. $\pm 0.1$ ha.	a. as required b. average	a. 30 m b. $\pm 0.1$ ha.	1. direct field measurement	1. aerial photo interpretation 2. field surveys	soil, vegetation, soil moisture - T-11 camera RC8 camera	0.5-0.7 $\mu$ color & B&W 0.4-0.7 $\mu$ color IR
<u>GROUNDWATER</u> <u>CHEMICAL QUALITY</u> for salt balance and salinity changes	a. total dissolved solids b. varies c. $\pm 10 \text{ mg/l}$	a. as required b. average	a. NA b. NA	1. sampling & lab. analysis 2. electro-chem. probe	1. lab. analysis 2. field measurement	-	-
<u>SALT WATER</u> <u>INTRUSION</u> for groundwater basin management	a. location & flux b. $\text{m}^3/\text{m}^2$ c. $\pm 10\%$	a. as required b. average	a. NA b. NA	1. field observation in test wells	1. water levels in saline fresh water zone	-	-
<u>SPECIFIC YIELD</u> <u>SPECIFIC RETENTION</u> for groundwater basin characteriza- tion	a. sp. yield b. percent c. $\pm 1\%$	a. as required, once b. average	a. NA b. NA	1. undisturb. soil sample & analysis	1. lab. analysis	-	-



testing and in ground truth study, and in exploring other methods and procedures for utilizing new data sources in operational programs will contribute in great measure to the eventual success of the research effort.

### 3.3 FUTURE PROPOSED WORK

Broadening of the scope of the current analysis of hydrologic systems to include greater emphasis on the aquatic components of water resource systems has been accomplished as noted in this progress statement. Consistent with this intent it may be noteworthy that at the state level an extensive monitoring program is presently being updated and reprogrammed to meet more rigorous requirements for management of water resources in all areas of environmental interest. We are, therefore, provided with an excellent opportunity to expand the ongoing research efforts of the U.C. Integrated Study and the activity of the Davis Campus research team to this vital sector of the management of the state's resources.

The studies outlined under the expanded scope of the program defined in the May 1, 1970 Annual Report and detailed in the ERTS and Skylab proposals previously submitted can be implemented immediately if we are given the support augmentation requested.

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## Chapter 4

### REMOTE SENSING DATA AS AN AID TO RESOURCE MANAGEMENT IN NORTHERN CALIFORNIA

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#### 4.1 INTRODUCTION

During this funding period two major studies are being carried out in Northern California, namely:

(1) Measurement of hydrologic resource parameters through the use of spacecraft and aircraft data in the Feather River Headwaters area (See Plate 4.1).

(2) Analysis of the Northern Coastal Zone Environment with the aid of spacecraft and aircraft data (See Plate 4.2).

An explanation of the objectives and relationship between Item (1), above, and certain of our previous studies can be found in Chapter 4 of the 1971 Annual Progress Report for the Integrated Study. The following text provides background information and defines the objectives of the analysis of the Northern Coastal Zone Environment.

##### 4.1.1 Background

It is becoming increasingly apparent that the coastal zone of California is in itself an important resource. As population increases, the coastal lands will come under mounting pressure for development, both as a place of human habitation and as a place for more intensive





use and development of natural resources. From San Francisco southward, the coast is already the site of numerous urban centers, and the problem of planning entails not only how to plan for future development, but also how to deal with currently existing development. In many ways the northern coastal region presents somewhat different problems. In general the north coast (consisting of the counties of Marin, Sonoma, Mendocino, Humboldt, and Del Norte--see Plate 4.2) is relatively rural, with an economy based on agriculture, timber, commercial fishing, and tourism. However, it is expected that intensive resource use resulting from increasing population will soon become a serious problem unless wise land use planning is undertaken. Thus the north coastal zone presents an excellent opportunity for intelligent, informed planning of development before intensive land use activities become widespread.

One prerequisite of intelligent land use planning of any region is a detailed and comprehensive knowledge as to the environment of the area in terms of its effect on potential resource management and use. In the north coastal area, one urgently needed type of information is an integrated inventory and evaluation of the physical characteristics of the region as they relate to the suitability for various types of land use.

Due to the fact that the bulk of the region can be classified as essentially wild land, the capabilities of the Forestry Remote Sensing Laboratory, Berkeley Campus, lend themselves particularly well to investigations of the ways in which remote sensing and other supporting data

may be used in conducting such potential land use evaluations.

#### 4.1.2 Objectives

The purpose of this study is to evaluate the usefulness of remote sensing data in providing general land-use planning information pertaining to the coastal zone of Northern California. The test area covers the entire coast of California extending from the San Francisco Bay Area to the Oregon border.

In particular, we are attempting to enumerate those physical parameters of the landscape which are of particular importance in determining the potential of an area in terms of land use, be it natural resource utilization, urban development or industrial development. This determination is being made with a consideration of the needs of land-use planners now involved in the formulation of long range land-use plans. A quantitative evaluation will then be made of the degree to which these parameters can be mapped or otherwise extracted from remote sensing data by means of both human interpretation and automatic feature classification. In conjunction with this information extraction phase, attempts will be made to utilize our computerized "data bank" for storage and retrieval of the information thus derived such that it might provide maximum utility for the ultimate users. Finally, the results of the experiment will be evaluated in terms of the information and accuracy requirements of those agencies actually responsible for the formulation of land-use plans in the north coastal region.

The experiment is structured such that initial work is centered on gross features which almost certainly can be identified on high altitude spacecraft and aircraft imagery, and will progress to more detailed



features. Thus it will be possible to ascertain that point at which small scale imagery with poor spatial resolution must be supplemented (through some form of multistage sampling) with other types of data in order to provide the required detail of information. In those cases where the required parameters cannot be directly measured, an attempt will be made to ascertain ways in which initial stratification using small scale imagery can be of aid in determining the optimum allocation of subsamples in the form of aircraft photo coverage or on-the-ground surveys.

#### 4.1.3 Approach

Our experience to date has convinced us of the necessity to use a systems concept and team approach in solving problems of interest to the earth resource manager. Consequently, the Forestry Remote Sensing Laboratory has been organized to include five functional units (see Plate 4.3). These units address themselves to the most important problems which must be solved if a remote sensing system is to be employed successfully for earth resources inventory purposes. The five problem areas investigated under this team approach are as follows:

- (1) determination of the feasibility of providing the resource manager with operationally useful information through the use of remote sensing techniques;

- (2) definition of the spectral characteristics of earth resources and the optimum procedures for calibrating multispectral remote sensing data acquired of those resources;

- (3) determination of the extent to which humans can extract useful earth resource information through a study of remote sensing imagery

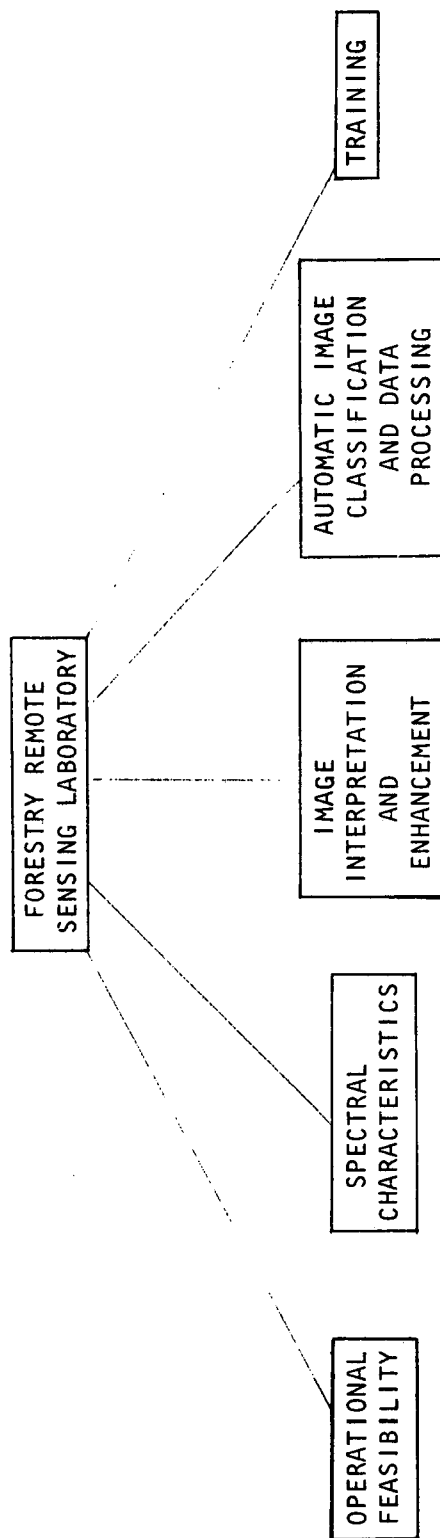


Plate 4.3 Organizational diagram of the Forestry Remote Sensing Laboratory, University of California, Berkeley, California.

either in its original form or when enhanced by various means;

(4) determination of the extent to which automatic data handling and processing equipment can extract useful earth resources information from remote sensing data; and

(5) effective dissemination of remote sensing results through the offering of various kinds of training programs in which the interaction between users and scientists can be emphasized.

The units of our Forestry Remote Sensing Laboratory which are engaged in these five problems are, respectively: (1) the Operational Feasibility Unit, (2) the Spectral Characteristics Unit, (3) the Image Interpretation and Enhancement Unit, (4) the Automatic Image Classification and Data Processing Unit, and (5) the Training Unit. Consistent with this team approach the remainder of this Chapter consists of five parts which are devoted, respectively, to the progress reports of these five units.

#### 4.2 REPORT OF THE OPERATIONAL FEASIBILITY UNIT

The primary areas of responsibility of the Operational Feasibility Unit consist of: (1) definition of specific problem areas upon which efforts of the Forestry Remote Sensing Laboratory might best be focused in light of operational needs of the prospective data user, (2) determination of optimum methods for evaluating remote sensing techniques, and (3) evaluation of techniques developed by other units of the FRSL in terms of their actual usefulness to potential users of remote sensing data.

As was discussed in previous progress reports, the efforts of the Unit during the first year of this study centered around the compilation

of a list of physical parameters important in terms of the hydrologic phenomena occurring in the Feather River watershed, and which were of interest to watershed management planners. This list was developed in cooperation with Professor Burgy and his colleagues at the Davis campus, and was meant as a guide for the technical units of the FRSL in choosing those specific interpretation problems upon which to focus their efforts. It was decided that the technical units would attempt various mapping processes using the available small scale imagery of the test site, and that techniques would be developed to allow quantitative determinations of the accuracy of such mapping.

#### 4.2.1 Work Performed During the Period Covered by this Report

##### Field Data Collection

In cooperation with the Image Interpretation Unit, a system for ground data collection in the Feather River watershed was developed. The objective of this data collection process was to gather sufficient information pertaining to the physical parameters of the areas that were to be subsequently mapped on aerial photography to allow a quantitative evaluation of the accuracy of the mapping to be performed.

Ground data were collected at a number of ground plots which were systematically located (with a random start) throughout the 3600 square miles of the upper Feather River watershed. Eighty plots scattered regularly throughout the entire watershed are to be used in testing those general mapping procedures which will involve the entire test site. In addition, five smaller watersheds, comprising approximately 20% of the total area, were intensively sampled with an additional 80 plots. It is planned that these "sub-watersheds" will be the subject

of tests involving fairly detailed mapping procedures. Thus a total of 160 ground plots were established.

Through use of the list of relevant parameters which had been compiled earlier, a set of classification information to be collected at each plot was established. This included: (1) vegetation-terrain type, (2) density of vegetation cover, in percent, (3) species composition, (4) average canopy height, (5) geologic type, (6) soil depth and color, (7) aspect, (8) slope, and (9) elevation.

All of the data collected by the field crews have now been tabulated. The tests of mapping accuracy will proceed upon completion of various terrain feature maps to be produced by the II&E and ADP Units. A more detailed description of the ground data collection process and status of the interpretation and mapping which is underway can be found in the contributions to this report made by those two units.

#### Coastal Zone Studies

During the past six months the FRSL has begun studies into the potential of using small-scale aircraft and ERTS imagery for resource planning in the coastal zone of northern California. As population increases, these coastal lands will come under mounting pressure for development, both as a place of human habitation and as a place for more intensive use and development of natural resources. The north coast counties--Marin, Sonoma, Mendocino, Humboldt and Del Norte--are relatively rural, with an economy based on agriculture, timber, commercial fishing and tourism. However, it is expected that intensive

resource use resulting from increasing population will soon become a serious problem unless wise land use planning is undertaken. Thus the north coastal zone presents an excellent opportunity for intelligent, informed planning of development before intensive land use activities become widespread.

#### A. Review of County Plans

To date our efforts have been directed toward gathering county statistics and reviewing the existing county master plans in order to determine the potential value of small scale remote sensing data in county and regional planning. A summary and evaluation of these plans is presented below:

1. The most current master plan for Del Norte County, written in 1965, is now being revised due to the advent of the Redwood National Park and other regulations regarding land use. This represents a common problem facing most of the north coast counties. As prime commercial timberland is converted to parkland, the county must find alternate sources of income, because the economic return to the county on recreation land is usually much less than that from timber land with respect to employment and the tax revenue.

2. The master plans for Humboldt and Mendocino Counties have almost identical objectives. This is not surprising since both have forestry oriented economies which, with the present slump in the lumber market, are in decline. The objectives of Mendocino County plan are as follows:

#### COMMUNITY VALUES

- Sound neighborhood standards, designed for maximum convenience and safety.
- High quality of services: water, sewage, drainage, fire and police protection, streets and highways.
- Adequate open space, aesthetic controls, park, recreation and scenic highway developments.
- Educational and cultural facilities to meet growing demands.

#### ECONOMIC BASE

- Increased industrial activity for strengthened tax base, with proper types in proper locations.
- Expanded retail sales and services, wholesale and distribution.
- Increased local processing of area resources.
- Increased sustained yield operations in forestry.
- Increased production and processing of mineral resources.
- Increased agricultural production and processing.

#### PRESERVATION OF NATURAL RESOURCES

- Protection and planned use of natural scenic features.
- Provision for compatible private and public developments in, and access to, scenic and recreational areas.
- Conservation measures to protect natural resources.
- Appropriate land use planning and zoning to conserve and protect agricultural soils.

It should be noted that many of the objectives that are proposed to strengthen the economy of the counties will come under close scrutiny

by conservation groups throughout the state. This was quite evident in northern Humboldt County where a major timber company was pressured by conservationists and others to sharply cut back logging of redwood and Douglas fir in the north coast area even after the company's logging proposal was approved by the California State Board of Forestry. In addition to mining and logging practices, it can be anticipated that freeway and highway development proposals which both counties feel are needed for increased economic diversification will be watched closely by these same conservation groups in order that areas of natural beauty will not be unduly disturbed for the purpose of improving transportation networks.

3. Currently, there is no county wide master plan for Sonoma County. However, in July 1971 the county began a two year effort to develop such a plan under funding from national and state government sources. At present there are about 25 specific plans for sub-areas of the county which include city general plans, county traffic, sanitation and recreation plans, sanitation district plans and water distribution plans. Undoubtedly, many of these existing plans will be incorporated into the overall county plan.

4. The major concern of Marin County planners is that of preserving the environment. The exceptional environment of this county, which represents a bedroom community to San Francisco and a recreational area to the entire San Francisco Bay area, is suffering due to continuing increases in population pressure:



"It is also common knowledge that as Marin has grown, its environment has deteriorated. A drive along 101 today compared with last year reveals that there is a little less of the landscape left unbulldozed, communities with definite edges last year have now sprawled a little closer to a Los Angeles type of merge; and here and there ridge tops which only yesterday were topped by trees and grass now are capped by flatland houses hanging off new notches in a hillside."

The fear of becoming "a little closer to a Los Angeles type" and a realization that prompt action will be required to preserve the county's environment has brought about the publication of the most comprehensive master plan of all the five northern coast counties. It is evident that for the preparation of this plan, a thorough inventory of the county's developed and undeveloped land was made. From this information, the county was divided into six zones--coastal foothills, central uplands, inland valleys, bayside foothills, bayside plains and bay shore--upon which the merits of all development and zoning proposals should be evaluated. The following recommendations summarize the findings and specific proposals of the county planners:

(a) Marin's communities are identifiable with the natural subdivisions of the county and are separated by natural greenbelts of hills and ridges. This characteristic must be preserved before these communities expand into urban sprawls.

(b) Development should respect the sense of place created by the six basic land forms of the county.

(c) Protection of the local environment should be accomplished by a county-wide Environmental Impact Review Board with legal authority over environmental violators.

(d) Developmental controls are urgently needed now in the eastern urbanized corridor of Marin to save the existing open space.

(e) More controls are needed to regulate private development.

(f) A balanced transportation system should be developed to prevent further deterioration of the environment due to the automobile.

(g) Marin towns must strengthen their local identities.

(h) Incentives should be provided for meeting high standards of development.

(i) Maximum holding capacity on the land should be related to desirable transportation, utility, hydrological, open space and general livability objectives.

#### B. Potential Role of Remote Sensing in County and Regional Planning

The review of the county plans indicates that small scale aircraft imagery and ERTS type imagery might be a valuable tool to north coast county planners, but for different reasons for the different counties.

It appears that the four northern counties--Sonoma, Mendocino, Humboldt and Del Norte--still have an inadequate inventory of their total environmental complex. Small scale imagery would be useful in enumerating those physical parameters of the landscape which are of particular importance in determining the potential of an area in terms of land use, be it natural resource utilization, urban development or industrial development.

Marin County, unlike the other four, has a good inventory of those features which have a significant impact upon scenic resources, recrea-

tion and the general quality of life, so that small scale imagery for resource inventory purposes may be of little extra value. However, the synoptic view provided by such imagery could still be put to good use. First, it can be used in the evaluation of the relative merits of three regional plans already proposed for the county, viz., the ABAG (Association of Bay Area Governments) Preliminary Regional Plan, the BCDC (Bay Conservation Development Commission) and the Marin County Preliminary Open Space Plan. Secondly, the imagery might be a better medium than planning maps for use in presenting information to the public concerning the unfortunate consequences of past zoning policy decisions and the probable results of present zoning proposals.

Small scale imagery should be valuable to the entire north coast region in developing policy for open space allocation. All too often, the boundaries for such areas are coincident with political boundaries which have no ecological meaning. The synoptic view provided by this imagery should enable one to make a land classification system that would be applicable to the entire region, thus making it possible to delineate the meaningful land use boundaries required by regional planners.

#### Resource Mapping Evaluation Studies

A preliminary step was taken in the quantitative evaluation of maps made using small scale aircraft and ERTS imagery. (The evaluation will be an important part of our studies during the coming year.) This step entailed the surveying of methods of resource mapping evaluation

which have been used by researchers in the past. Our objective is to determine the utility of those techniques for specific kinds of mapping problems.

Forest stand delineation was chosen as a case study example for analysis. The preliminary step was an attempt to define exactly the need for forest stand maps by land managers, and accuracy requirements. This was accomplished primarily through personal interviews with both government and private employees directly involved with management decisions. In essence, the results of these interviews established the following:

1. Forest stand maps are indeed used on a regular basis for planning the management of forest lands both on a local, state or regional level. Uses range from layout of logging roads to stratification prior to regional inventory samples.
2. In general the users have adapted their use to fit the quality of map presently available. Nearly all agree that an improvement in accuracy would be desirable, but few are able to state definitely what gains or benefits would accrue from such improvement.
3. Due to the difficulty of determining marginal benefits, a strict cost-benefit ratio analysis to determine the usefulness of mapping from remote sensing data is nearly impossible. Probably the most fruitful approach is to attempt to demonstrate that in specific cases, increased map accuracy can be obtained at a cost less than or equal to that of

conventional techniques, thus avoiding the more difficult analysis entirely.

It has been our experience that these conclusions are not characteristic of foresters alone, but apply equally as well to most persons engaged in land management decisions.

Once it was established that a quantitative determination of mapping accuracy is a worthwhile objective, a literature survey was conducted, and various techniques used for resource mapping evaluation in relation to remote sensing analysis were investigated. There are surprisingly few papers which deal with this subject, a fact which may be indicative of the difficulty of the task. It appears that the major problems encountered are a lack of "ground truth" data for comparison, and the difficulty of determining the various kinds of interpretation or mapping errors which can be made.

In general, a map can be tested for accuracy (once ground truth is known), either on the basis of the location of delineation lines, or on the coincidence of delineated areas. In either case an analysis of the results is complicated by the fact that typing or mapping consists of two operations, namely, the drawing of boundaries between types, and the assigning of a particular identification label to each delineated type. In terms of ground truth, the problem stems from the fact that in most cases involving large areas, the only possible way to obtain comprehensive mapping data is through the use of aerial photos; hence there is difficulty in obtaining independent and objective information against which to evaluate the mapping procedure in question. Usually some method of sampling to obtain "ground truth" is necessary.

The literature review yielded two papers, one dealing with boundary coincidence testing methods (Vermeer, 1968)\* and one dealing with area coincidence methods (Young and Stoeckeler, 1956)\*\* , which presented some guidelines for a seemingly feasible evaluation technique. In order to combine both methods and try out a system using both boundary and area criteria, a test was carried out using a forested tract in Finland for which stand boundaries had been mapped on the ground by trained foresters and for which independent photo interpretation of forest stands had also been carried out. The objective of the test was not to evaluate the photo interpretation process, but rather to simply become acquainted with the testing procedures themselves in a pilot study, and to attempt to iron out troublesome details in the procedure before the techniques were applied to large areas such as the Feather River watershed in actual interpretation tests.

In conclusion it was felt that techniques for both boundary and area coincidence testing which will be used in the near future have been adequately developed, and that such tests can proceed as soon as interpretation results are available.

#### 4.2.2 Future Proposed Work

During the next six months, the efforts of the Operational Feasibility Unit will consist almost entirely of preparation for the analysis of ERTS-A data which should become available in mid-1972. Probably the most important aspect of our work will involve the coordination of the FRSL activities with those of persons in the State of California directly concerned with the analysis of ERTS-A data for

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\* Vermeer, J. 1968. Results of an objective comparison of film-filter combinations applied to an example of photo interpretation for soil surveys. Eleventh Congress of the International Society for Photogrammetry. Presented paper for Commission VII, Lausanne, Switzerland.

\*\* Young, H.E. and E.G. Stoeckeler 1956. Quantitative evaluation of photo interpretation mapping. Photogrammetric Engineering 22(1):137-143

purposes of actual land use inventories and management. Most of the state agencies involved with resource development and management are aware of the fact that ERTS data will be available. However, considerable education and coordination of tasks will be necessary during the next several months to ensure that ERTS-A data are used to maximum advantage. The role of the Operational Feasibility Unit will be to establish lines of communication between the FRSL and those state agencies concerned with land use planning and wildland resource management in order to ascertain which specific problem areas should be the focus of the research carried out by the FRSL. It is hoped that in this way the research capability of the FRSL and the operational capabilities of the state agencies can be combined in such a way that the best use can be made of ERTS data. In essence, tasks must be chosen which are both important in an operational sense, and for which ERTS data seem to be at least a possibly useful input.

ERTS data will probably be most useful for fairly gross land use delineations and as the initial stage in regional resource inventories which will require supplemental aircraft imagery or ground data for their completion. An important preliminary step would seem to be a determination of a common land-use delineation system which would be of use to as many different agencies as possible. Hopefully, such coordination would also result from our discussions with the state agencies.

In addition to these coordination tasks, the unit will assist in the quantitative evaluation of mapping techniques applied to small-scale

aircraft and simulated space imagery of the Feather River watershed which has been described previously. Again, these exercises should be viewed as a learning process in anticipation of similar analyses which will be applied to ERTS-A data when they become available.

#### 4.3 REPORT OF THE IMAGE INTERPRETATION AND ENHANCEMENT UNIT

The primary objective of the research being performed by the Image Interpretation and Enhancement Unit (IIE) of the FRSL is to develop and refine methods for extracting useful resource information from remote sensing imagery--using human photo interpreters. Thus, the many factors (i.e., film-filter, scale, resolution, etc.) which govern the perception and interpretation of imagery are being studied. By employing vigorous testing procedures when possible, we attempt to define the optimum combination of factors needed to solve specific resource inventory and/or monitoring problems with the aid of remote sensing. However, developing methodologies which may be applicable for resource surveys not only in different wildland regions of the United States but also in other parts of the world entails more than defining specifications for image acquisition and interpretation. We have found that we must define methods for (1) familiarizing personnel with the important resources of an area, (2) acquiring and preparing imagery for that area, (3) selecting photo interpreters, (4) training photo interpreters, (5) performing photo interpretation tasks, (6) compiling photo interpretation results, (7) collecting ground data information, (8) correlating ground and interpretation data, (9) eval-



uating interpretation results, and (10) disseminating results. Consequently, we are devoting considerable time and effort to the development of an understanding of the components of the entire image interpretation process.

Members of the II&E Unit at the FRSL have been studying for many years image interpretation techniques applied to wildland environments, particularly within the NASA Bucks Lake Test Site located in the heart of the Feather River Watershed. We now have the opportunity to test certain techniques, proven to be useful in that localized area, in the adjacent and analogous, but much larger, Feather River Watershed area, which is comprised of more than 2 million acres. Emphasis in the work that is being performed in the "extended" test area is being placed on developing methods for effectively utilizing low resolution, synoptic view imagery, similar to that which might be obtainable from ERTS and Skylab vehicles. Specifically, three kinds of resource surveys within the Feather River watershed area are being sought with the aid of human image analysis techniques. They are (1) vegetation/terrain surveys, (2) snow surveys, and (3) environmental change surveys. Progress made since our last reporting date, May 1, 1971, in developing and applying the components of the interpretation process to these survey problems is presented below.

#### 4.3.1 Work Performed During the Period Covered by this Report

##### Vegetation/Terrain Surveys

During this last year, personnel of the II&E Unit have concentrated their efforts on the following items which relate to the image interpre-

tation process: (1) familiarizing themselves with each vegetation/terrain type occurring within the Feather River Watershed and considered to be important by the hydrologist or watershed manager (for a complete listing, see the 1971 Annual Progress Report), (2) preparing RB-57 high flight imagery for use in various kinds of image interpretation, (3) preparing a series of interpretation training aids (i.e., image interpretation keys) that will allow an interpreter to train himself to detect, identify and delineate each important vegetation/terrain type seen on the imagery, and (4) collecting ground data information throughout the entire Feather River Watershed, which can be used to further train the image analyst and to correct and improve his interpretation results.

Copy transparency, 9" x 9", false-color infrared images (scales 1/120,000 and 1/60,000) and color images (scale 1/120,000) as well as black-and-white, multiband 70 mm images, procured during RB-57 Missions 100 (July 1969) and 139 (July 1970) are being used as input data in these studies. Among the many possible image formats which could be used for this work, two have been selected for purposes of intensive analysis--copy transparency stereo coverage, and a semi-controlled photo mosaic. These two formats represent state-of-the-art high altitude aircraft imagery and simulated earth orbital imagery, respectively. Interpretation training aids (i.e., reference materials) were prepared such that they could be used in conjunction with these imagery formats. For example, one of the interpretation keys is for 16 dominant vegetation/terrain types that are encountered in this vast area. These types are standing water, running water, marsh, dry grassland, meadow,

subalpine grassland, foothill chaparral, mountain chaparral, pine-oak woodland, mountain coniferous forest, red fir forest, sagebrush, juniper woodland, bare rocky areas, urban, and agriculture. The key includes both a general description and a terrestrial photograph of each type. In addition, training examples have been plotted directly on the photo mosaic and on the 9" x 9" transparencies. We are currently in the process of applying these training aids as we attempt to map vegetation/terrain types, first on the mosaic (minimum mapping area = 640 acres or one square mile), and then on the copy transparencies (minimum mapping area = 100 acres). The detailed mapping on the high-flight stereo imagery is being done only for secondary watersheds including the Spanish Creek Watershed which covers a major portion of the Bucks Lake Test Site.

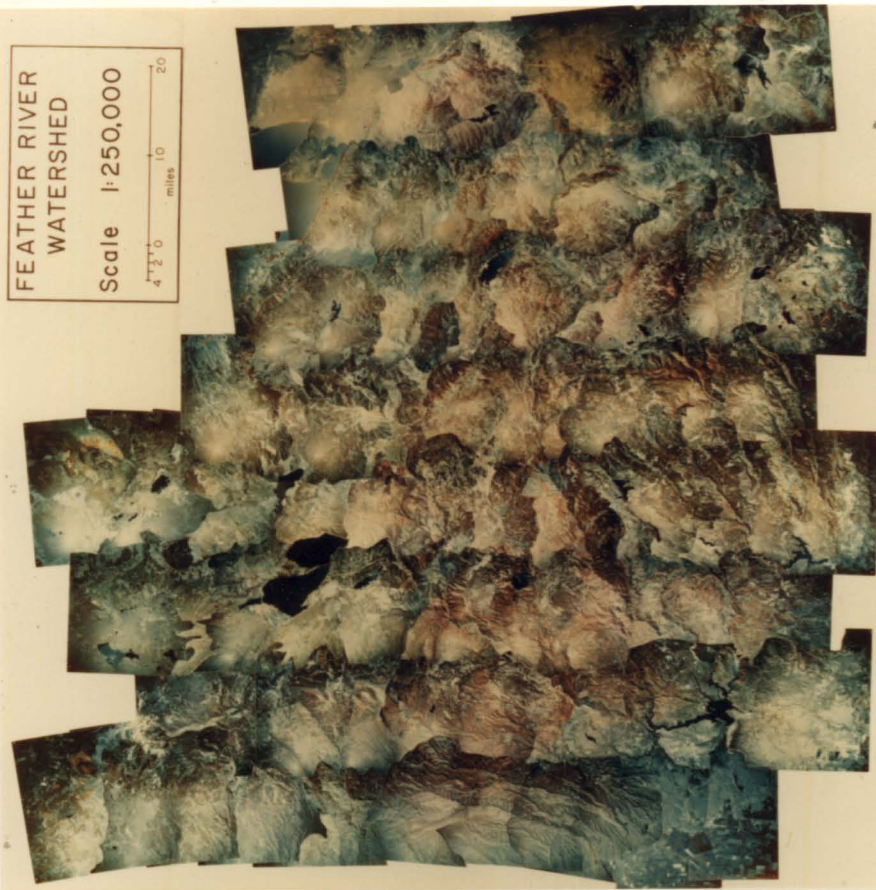
Once the task of image interpretation is completed, we will work closely with the Operational Feasibility Unit staff and attempt to evaluate the interpretation results in terms of type delineation and identification accuracy. However, it was decided that a vast amount of ground data would be needed to allow us to make such an evaluation. Thus, during the four-month field season last summer, members of the II&E Unit concentrated on gathering ground data representative of all major vegetation/terrain types found throughout the Feather River Watershed. A justification for this activity and a description of the procedures used have been presented in section 4.2 of this chapter. Suffice it to say, that nearly eight man-months of time and effort were expended to gather both point data and type data at 160 ground positions

systematically located throughout the Watershed (see Figure 4.1). Due to the Watershed's immense size, rugged terrain and lack of accessibility, the field crew used a number of modes of transportation (driving, boating, hiking, etc.) to reach each plot and collect ground data pertinent to this study. We found that more than 90% of the field crew's time was used to travel (with the aid of high-flight imagery in hand) from one plot on the ground to the next. Once the crew reached a ground plot, it was a relatively simple matter to record observations and measurements and procure representative terrestrial photographs of the site. The information gathered was recorded on 5" x 7" index cards (see Figure 4.2). In the future as additional ground data are collected, the information appearing on these cards (written on the card and coded on the card's border) easily can be transferred to IBM cards and entered into a computer. The information then can be efficiently and economically stored, retrieved, analyzed and correlated with image interpretation results.

#### Snow Surveys

The objectives of our snow survey work in the Feather River Watershed area are twofold--viz., developing optimum image interpretation techniques for delineating snowpack on sequentially procured small scale, synoptic view imagery, and determining the accuracy with which snowpack boundaries can be delineated. Work performed during the winter of 1970-71, and reported upon in the May, 1971, Annual Progress Report, involved (1) becoming familiar with snowpack conditions occurring within

FEATHER RIVER  
WATERSHED  
Scale 1:250,000  
4 2 0 miles



NOT REPRODUCIBLE



Figure 4.1. A reproduction of a semi-controlled photo-mosaic (original scale 1/250,000) made from high-flight color infrared transparencies is shown here (left). The entire Feather River Watershed area, comprising over 2,250,000 acres of wildland, has been outlined on the topographic map (right). Note the location of ground data collection points marked on the map. Despite the fact that 8 man-months were required to visit each ground position, there is only one low density plot for every 40.5 square miles of wildland area and only one high density plot for every 9 square miles of area (in the sub-watersheds). The number of plots was doubled again in the Spanish Creek Watershed so that there is one plot for every 4.5 square miles of area. These figures help illustrate the magnitude of the task of collecting ground data for an area as large as the Feather River Watershed.



(front of card)

SURVEY: A PLOT #: 10 DATE: 19 July 1971 CREW: JPM & RMC

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Veg.-Terrain Type: Mountain Chaparral Geology: Volcanic

Veg. Cover %, All Veg.: 95% Soil Depth: 1 1/2'

Veg. Cover %, Trees: 25% Soil Color: 10YR 4/3

Veg. Cover %, Shrubs: 90% Aspect: flat

Veg. Cover %, Herbaceous & Grass: 5% Slope: flat

Avg. Canopy Ht., All Cover: 10' Elevation: 4500'

Avg. Canopy Ht., Trees: 40' Location

Survey: T28N R8E Sec. 15

UTM: Chester Quad

(back of card)

SPECIES PRESENT

TREES: Pinus ponderosa, Abies concolor

SHRUBS: Arctostaphylos patula, Ceanothus cordulatus, Ceanothus prostratus

HERBACEOUS: Grasses, flowers (Compositae)

REMARKS: Brush field with scattered pine and fir coming in. Very few old trees. Some disease in the pines. Site seems pretty good based on yearly growth on young trees.

AERIAL PHOTO #: 2 195

GROUND PHOTOS: 1-6-11 thru 13

Figure 4.2. Ground data were collected for 160 preselected plots and recorded on field cards such as the one shown here. The information written on the card can also be punched onto the card's border using a digital code; therefore, specific information relative to ground locations or type characteristics can be rapidly retrieved.

the study area, (2) acquiring at 5 different dates small scale (1/100,000) 70 mm photography taken of the Spanish Creek Watershed (Bucks Lake Test Site), (3) preparing the imagery for analysis, (4) training an image analyst to recognize snow boundaries when their appearance can be greatly influenced by a variety of terrain features or conditions, (5) performing the interpretation task using a viewer-enlarger, and (6) compiling the interpretation results. Examples of the small scale imagery are illustrated in Figure 4.3; note that for the particular region illustrated in this example, the task of delineating on sequential imagery an accurate snow boundary appears to be a simple one. However, one component of the interpretation process was missing during last year's work, namely, the collection of ground data which can be used to further train the image analyst and evaluate his results. Consequently, we do not know if the plotted boundaries indicated in Figure 4.3 are in the correct position, and without adequate ground data it is impossible to determine this. For example, we learned that four environmental factors greatly influence the appearance of a snow boundary, viz., elevation, slope, aspect and vegetation/terrain type. The photo illustrations in Figure 4.4 show these relationships. Note that the snow boundary in certain areas appears to follow a line of equal elevation but drops down in elevation considerably on north facing slopes. Furthermore, the presence or absence of snow and consequently the snow boundary are (1) easily detectable in meadows and bare areas, (2) sometimes but not always detectable in sparse coniferous forest and (3) nearly impossible to detect in dense coniferous forest.

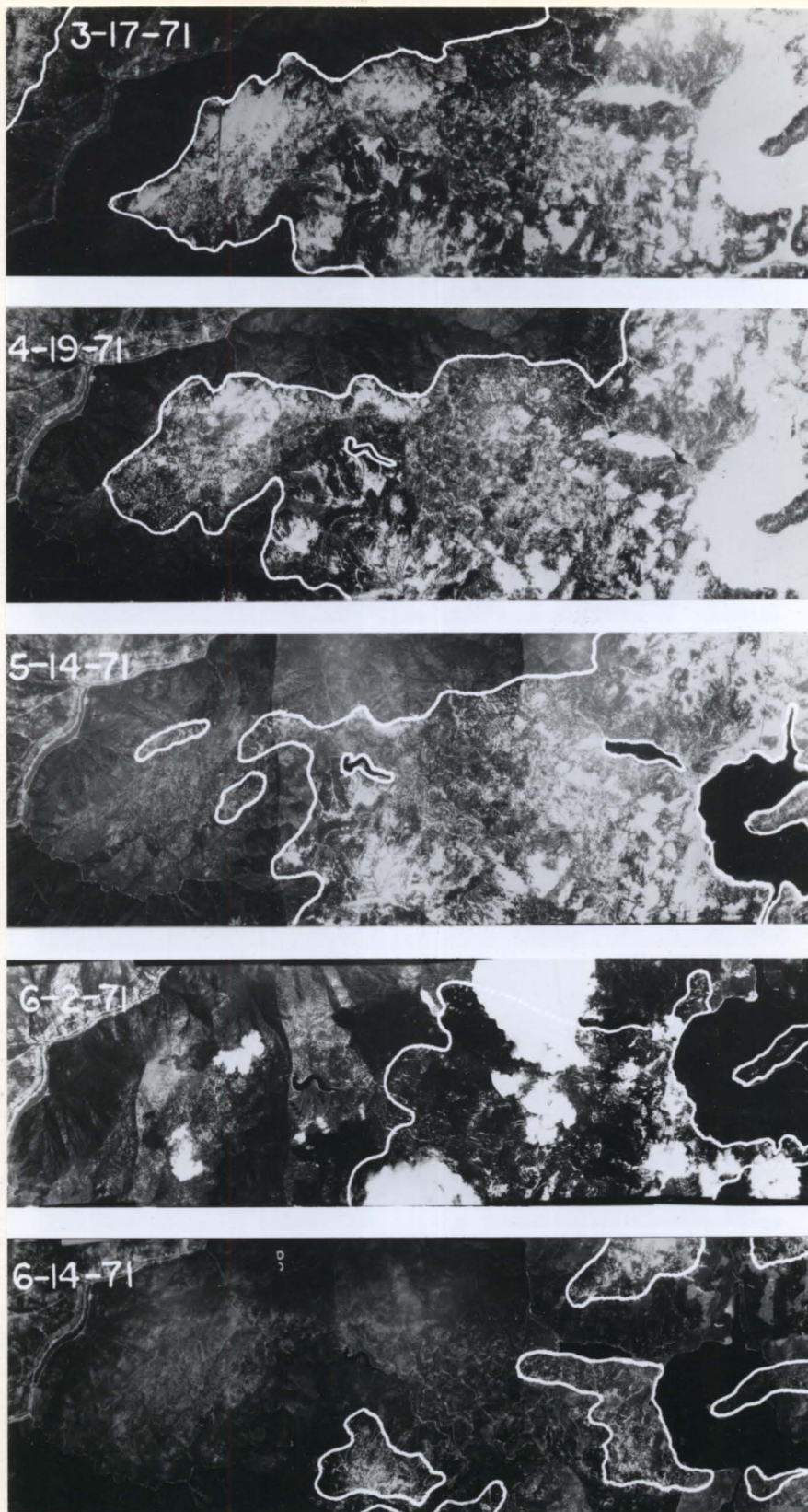
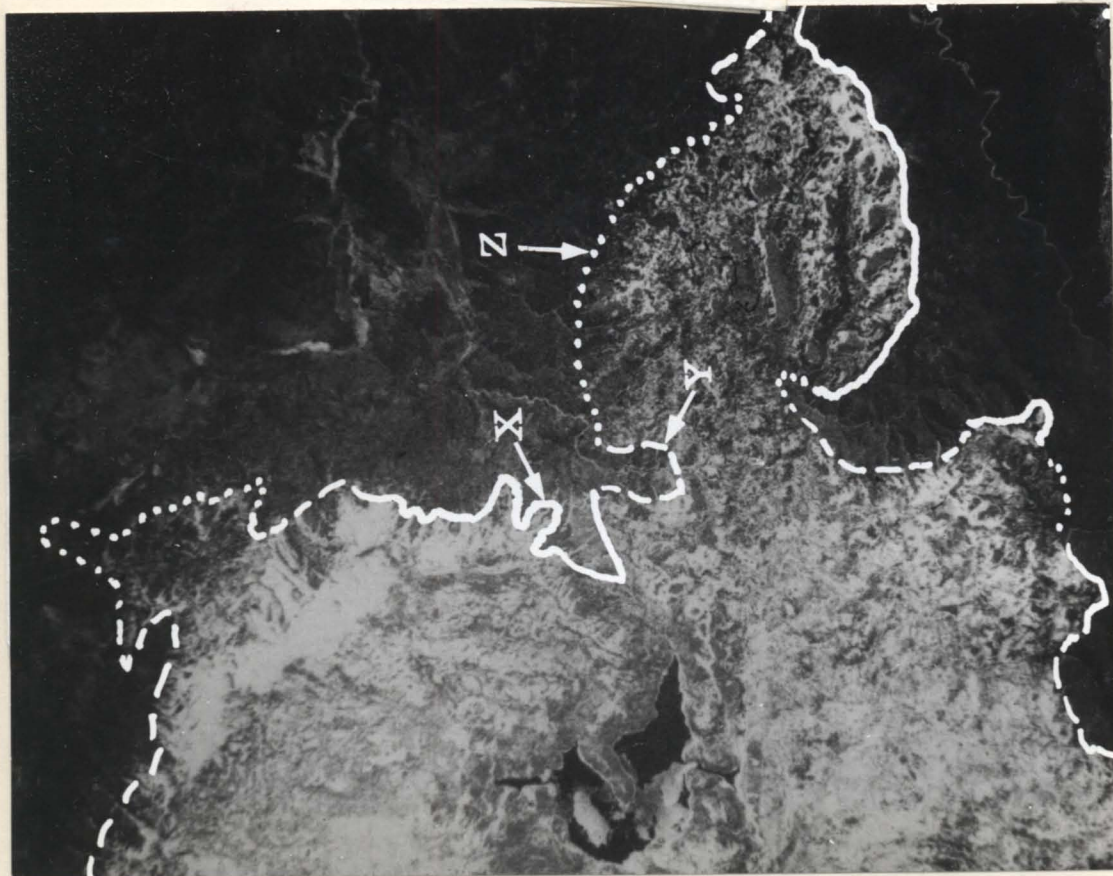


Figure 4.3. The photo mosaics shown here (original scale 1/100,000) illustrates snowpack conditions between the North Fork of the Feather River on the left and Bucks Lake on the right. Note that an interpreter has estimated the position of the snowpack boundary on each set of imagery.





May 21, 1969

Figure 4.4a.

The U-2 photo examples shown here illustrate the relationships that exist between the appearance of snow as seen on small scale imagery (1/165,000) and vegetation/terrain conditions. On the May photo the snow boundary has been mapped where it is conspicuous (solid line), partially obscured (dashed line) and totally obscured (dotted line). Note that the appearance of the boundary can be correlated with various vegetation types seen on the color infrared photograph taken in August (e.g. conspicuous boundary and brushfields at point X, partially obscured boundary and sparse conifer forest at Y, and totally obscured boundary and dense conifer forest at Z). A vegetation type map made from color infrared photography is shown in Figure 4.4b, and a portion of the snow boundary shown here has been plotted on that map.



August 5, 1969



NOT REPRODUCIBLE



Figure 4.4b. The snow boundary mapped on U-2 high-flight photography taken in May 1969 has been plotted onto this vegetation type map. Note that the appearance of the boundary closely correlates with the vegetation type within which it occurs. General cover types are: #1 = very low density conifer forest and brushland, #2 = high density conifer forest, #3 = medium-density conifer forest, #4 = bare ground or rock and #5 = meadowland. See Figure 4.4a for an explanation of points X, Y and Z.

Nevertheless, if the image analyst were properly trained to recognize various combinations of environmental conditions, and if he were aware of the relationships between these various conditions and the appearance of snow associated with them, he probably could accurately place a snow boundary around the existing snowpack as seen on small scale imagery. The principal objective of our work this next winter will be to develop the necessary training aids which will allow an interpreter to efficiently and accurately map the areal extent of snow.

#### Environmental Change Surveys

The interpretation tasks relating to mapping environmental changes on small scale, low resolution imagery have been completed and the results were reported briefly in the May 1971 Annual Progress Report. The purpose of this work was to determine the feasibility of monitoring, changes in the landscape which occur in a wildland area. Since (1) both "man-made" and "natural" changes greatly influence the quality of the environment, especially in relatively undisturbed wildland areas, and (2) sensor-equipped earth orbital vehicles some day soon may provide periodic "looks" at vast wildland regions, we decided to define, as well as we could, the image characteristics of a variety of man-made changes (caused by urbanization, timber harvest, brush field manipulation, reforestation, grazing practices, agricultural projects, recreational development and mining operations) and natural changes (caused by fires, floods, erosion, wind and snow). An interpreter was given five sets of small scale, low resolution imagery (mainly conventional photo index sheets), spanning 29 years, and was instructed to

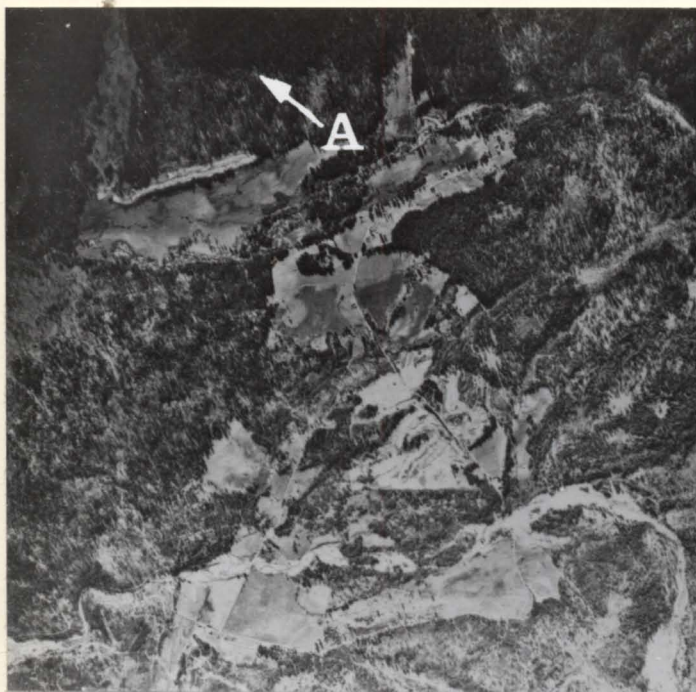
delineate and identify environmental changes. The time intervals between successive photo coverage were 10 years (1941-1951), 5 years (1951-1956), 10 years (1956-1966) and 4 years (1966-1970), respectively.

Photo examples taken in 1941, 1951, 1956 and 1966 are shown in Figure 4.5, and land areas which appear to have undergone change since the previous photo was taken, have been identified.

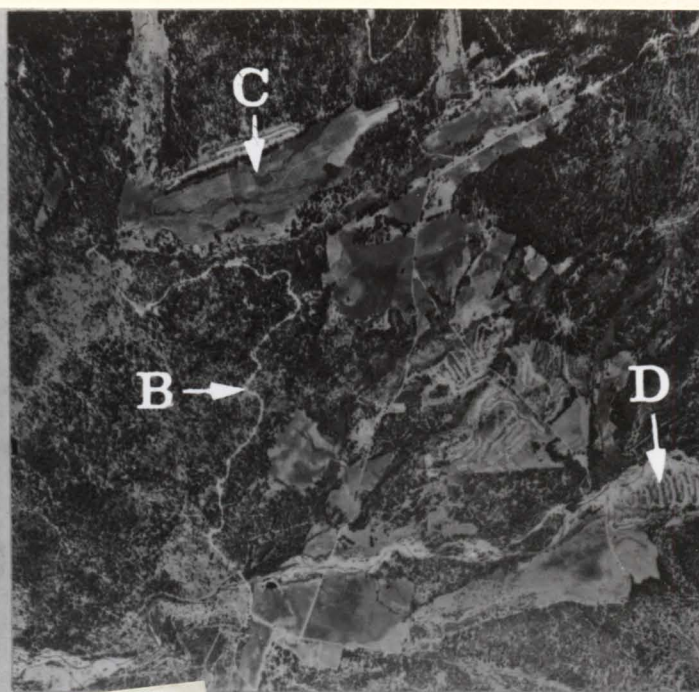
Thus, for each successive time interval, the interpreter generated a map-overlay showing changes that had taken place for that time period. Interpretation results, derived from the map-overlays, have been tabulated and presented in Table 4.1. It is interesting to note that for enormous land areas, historical data on environmental change and, more importantly, information on rate of environmental change, can be efficiently procured in this manner. For example, note that the interpreter concluded that the most detrimental "man-made" changes in the landscape, which were caused by mining, ceased to exist after 1951. In addition, the interpretation results indicate that the most significant change occurring in the landscape over the entire 29 year period was caused by timber management (selective logging by tractor), and that management of brush fields was non-existent prior to 1956.

It was very difficult during this study to determine the accuracy with which the interpreter mapped environmental changes. Few records which could be used as reliable "ground truth" are available for this remote region. In fact, the aerial photography may, in many instances, be the only permanent record containing reliable historical data about the area. Note that the interpreter determined that each year roughly



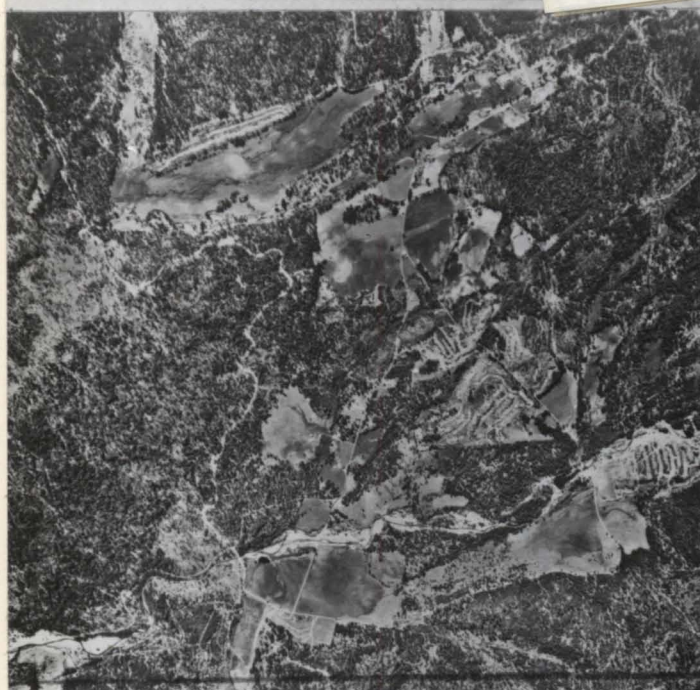


October 1941

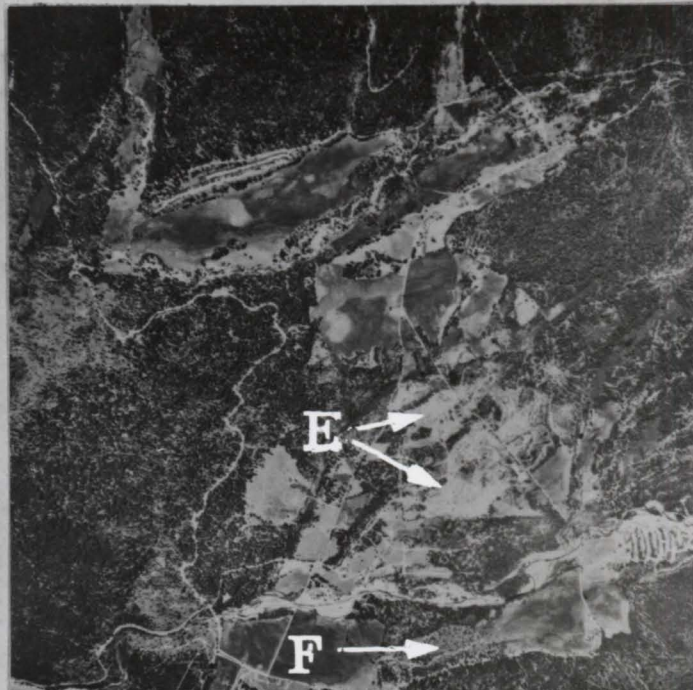


August 1951

NOT REPRODUCIBLE



September 1956



June 1966

Figure 4.5. Of the entire study area, only a small portion -- 150,000 acres of landscape at the Bucks Lake test site -- is shown here on 1941, 1951, 1956 and 1966 photography. Photo index sheets (scale 1/60,000) composed of hundreds of photos similar to the ones shown here were analyzed for purposes of mapping sequentially environmental change in a remote, wildland area. Tabulated interpretation results are given in Table 4.1. (Note the timber harvest boundary at A, a new logging road at B, agricultural harvesting patterns at C, mining activity at D, urbanization at E and evidence of plant succession at F.)

TABLE 4.1 ENVIRONMENTAL CHANGE SURVEY DATA: 29 YEARS

Categories	Time Periods			
	1941-51	1951-56	1956-66	1966-70
Fire	750 acres 0.048%	625 acres 0.084%	- -	- -
Erosion	- -	85 acres 0.011%	- -	- -
Urbanization	79,5 acres 0.005%	- -	20 acres 0.001%	- -
Timber Management	11,400 acres 0.76%	5560 acres 0.74%	22,200 acres 1.48%	4300 acres 0.716%
Agricultural Development	40 acres 0.003%	- -	- -	- -
Brush Conversion	- -	- -	1800 acres 0.12%	315 acres 0.05%
Mining	50 acres 0.003%	- -	- -	- -
Water Management	- -	- -	820 acres 0.055%	- -

Results have been presented as land area changed during each time period (acres) and percentage of land area changed per year during each time period (percent).

1% (on the average) of the entire 150,000 acre area studied was selectively harvested (for timber) over the 29 year period. We have concluded that this is a reasonable estimate for cutover timberland since (1) about half the area is composed of merchantable timberland and the U. S. Forest Service, managing most of this land, is utilizing approximately a 30 year cutting cycle (this would equal a 1.6% change per year for the entire area caused by timber harvest), and (2) the majority of cutting boundaries shown on U. S. Forest Service historical maps (see Figure 4.6) were recognized and plotted by the interpreter. The interpreter's acreage estimates regarding harvested timberland are slightly below the figure calculated with the aid of cutting cycle data, and some boundaries seen on the USFS maps were missed. Many errors occurred, however, because the harvest was either unusually "light" or because it immediately followed a photo mission. In the latter instance many years passed and natural reforestation took place before the next series of photos were taken. In addition, many of the harvest patterns were obscured by the tonal discontinuities appearing on the index sheets. This problem is unavoidable when many photographs are placed together to form a single photo mosaic. Despite that fact that the resolution of spaceborne imagery may be low, both of the problems mentioned here could be eliminated given sequential, synoptic view ERTS-A and/or Skylab imagery.

#### 4.3.2 Future Proposed Work

##### Vegetation/Terrain Surveys in the Feather River Watershed

Now that we are familiar with the hydrologically important vegetation/terrain resources for the entire Feather River Watershed area,



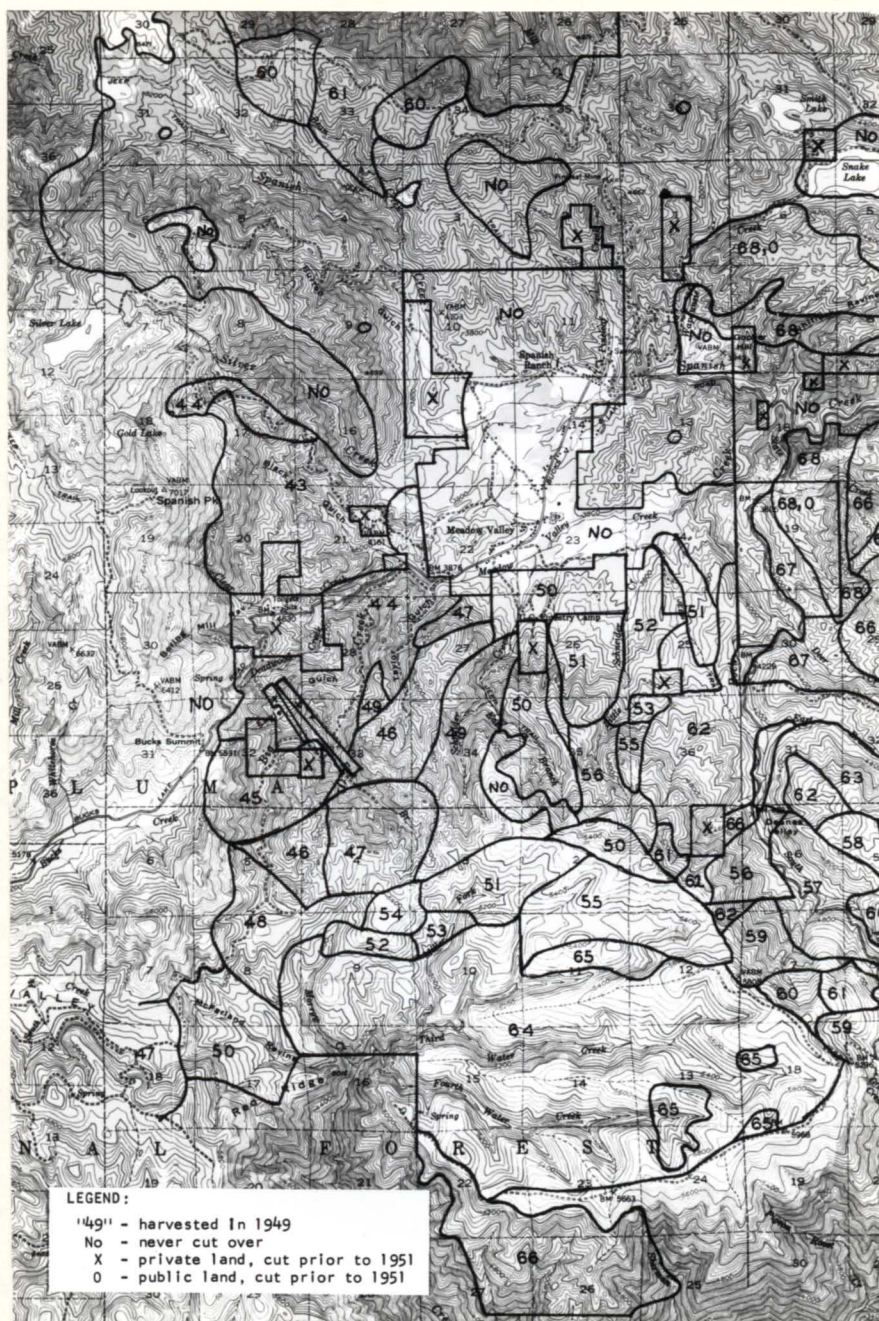


Figure 4.6. Very little historical information on each environmental change category is available for the study area. The map shown here is a U. S. Forest Service record of the cutting history in the Meadow Valley Working Circle; however, this map covers only a portion of the 150,000 acre study area and is very incomplete prior to 1951.



and now that imagery has been acquired and prepared for analysis, and suitable interpretation training aids have been prepared, we can conclude activities relating to another component in the interpretation process, that of performing the photo interpretation tasks. Within the next few weeks, and well before our next reporting date in May 1972, we will have generated for the entire 2-1/4 million acres a series of map overlays to the mosaic, showing major management units and a variety of vegetation/terrain categories. In addition, detailed map overlays will be made for each of the five sub-watersheds using state-of-the-art high-flight imagery. Since large amounts of ground data were collected during the last field season, personnel from both the II&E Unit and Operational Feasibility Unit will be able, immediately upon completion of the interpretation, to begin to correlate ground data with interpretation data. Thus, a thorough evaluation of the precision and accuracy associated with the interpretation results will be made. Each vegetation/terrain survey map will be thoroughly evaluated, with the aid of quantitative statistical methods, and definitive statements will be made concerning their accuracy and, therefore, usefulness.

Vegetation/Terrain Surveys in the Coastal Zone of California--  
Development of Techniques for State-Wide Monitoring of  
California's Annual Grassland

During the period March 31 to April 2, 1971, the NASA RB-57 aircraft acquired high quality, small scale (1/100,000) color and color infrared aerial photographs of about 40% of the State of California. This high resolution photography showed most of the California Annual Grassland associated with the Coast Mountain Range, extending from Ukiah

in the north, westward to the coast and southward to the Tehachapi Mountains. It provided an unequalled opportunity to (1) view a substantial geographical portion of California's Annual Grassland (there are between 20 and 25 million acres of annual grassland in California) at essentially the same time of year, and (2) to make observations regarding the gross phenology and development of the grassland in various climatic zones, on different topography, and at different elevations, exposures and soil types.

Certain correlations between the physical environment of an area, and the development of the forage crop were readily discerned. For example, the forage crop had already matured and dried in areas which had received only 4" to 6" of rainfall; in areas receiving 8" to 12" of rainfall the forage crop was mature and appeared green on all areas of deep soils and north east exposures, but the crop had dried on shallow soil sites and on southwest exposures. Furthermore, the forage crop had not yet reached peak production or maturity in areas which had received more than 12" of rainfall.

Thus, a preliminary investigation was initiated to determine the feasibility of obtaining and interpreting small scale imagery, taken at frequent intervals during the life cycle of the annual grasses, to monitor changes in gross plant development. The objective of this study was to determine whether, with the aid of synoptic view, low resolution photography, models could be formulated to predict deviations in forage production from an average forage crop, thereby

predicting the amount of forage produced for the entire California Annual Grassland in any given year.

Because of limited ground data for the entire California grassland area, the success of such a prediction model had to be based only upon ground and aerial observations made throughout several annual growth cycles at a few locations, and on certain theoretical concepts.\* Nonetheless, sufficient evidence existed to outline the framework of the model. Basic premises upon which the framework of the model depended were as follows:

(1) The annual forage crop progresses through a series of growth stages which are predictable. Specifically, in any geographical area, the seeds for the crop germinate in the autumn in response to about 1/2" of rainfall. The amount of growth immediately following germination is dependent upon the temperature. Growth ceases or is very slow throughout the winter because of cold temperatures. With warming spring temperatures, growth accelerates. During the spring, the plants reach a point of peak foliage development, they flower, mature and then dry.

(2) The timing of each growth stage, and the length of the growth cycle is controlled primarily by the timing of rainfall, the amount of rainfall and fluctuations in the temperature.

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\*Carnegie, D. M., Roberts, E. H. and R. N. Colwell, 1966. The Use of High Altitude, Color and Spectrozoal Imagery for the Inventory of Wildland Resources; Volume II of III: The Range Resource. Forestry Remote Sensing Laboratory, School of Forestry and Conservation, University of California, Berkeley.

(3) The production of forage from one year to the next also is controlled primarily by the timing of rainfall, the amount of rainfall and temperature fluctuations. A number of production curves could be drawn which would reflect the amount of forage production that is associated with various inputs of rainfall and temperature.

(4) Two periods during the life cycle of annual plants must be monitored because they provide the key to making predictions of forage production. The first period occurs in the autumn when the crop germinates; the second period occurs during the spring when the crop reaches a point of near-peak foliage development.

(5) The highest yield of forage crops occurs when, because of early rains, most of the grass seeds germinate early in the autumn, ample moisture continues to be available, and fairly warm temperatures prevail for good growth prior to winter. Ample and well distributed rainfall throughout the spring will prolong the growth period and the time of maturity, resulting in high forage production. The lowest yield of forage crops, on the other hand, occurs when most of the seeds do not germinate until late in the autumn and the young plants do not have much time in which to grow prior to the onset of cold winter temperatures which curtail further growth. If rainfall is scarce during the spring, and if this condition is accompanied by unseasonably warm temperatures, the available moisture will be quickly depleted resulting in a short growth period and early maturity.

(6) In any given geographical portion of the annual grassland, the average time of germination, the average time of maturity and the

average forage crop (expressed in pounds of forage produced per acre) should be rather well known. Furthermore, the extremes in forage production (the best and the poorest crops) should also be known, thereby placing limits upon the amount of forage which one could expect within any geographical area.

(7) The inputs to the prediction model are the time when the crop germinates, and the time when the crop reaches near-peak foliage development. Because of unequal distribution and amount of rainfall over the large area occupied by the annual grassland, these times will vary from one geographical area to another. Hence a monitoring system is required (based, for example, on the use of high altitude aircraft or spacecraft), which can provide a "picture" of the entire grassland area at frequent intervals during (a) the autumn, between October 1 and November 30, and (b) the spring between mid-February and mid-May.

(8) The time of seed germination in the autumn is easy to monitor. The annual range which remains dry during the summer will suddenly appear green. Determining the time of near-peak foliage development is a little more difficult--but this can be accomplished quite accurately by means of image interpretation.

(9) The stage of plant development referred to here as "near-peak foliage development" is an arbitrary, yet useful, term to denote that time during the growth period when the crop on various range sites in an area is undergoing very rapid change from flowering, to maturity, to drying. During this period the forage crop that is associated with

shallow soils, moderate to steep slopes and southwest facing exposures, dries earlier than that associated with deeper soils, bottomlands to gentle slopes and northeast facing exposures. At this time the contrast between the dry forage on shallow soil sites and the green forage (which is nearing the stage of maximum foliage development) on deeper soil sites is readily detectable on small scale photography. This dynamic condition of rapid change occurs during an interval of about two to four weeks each spring. It may occur at different times at different geographical areas, however, depending upon the amount and distribution of rainfall for a given year. Furthermore, it may occur at different times within a given geographical area depending upon whether or not the rainfall is average, below average, or above average.

(10) Because of differences in certain physical and biological characteristics which govern the environment of sites within a given area, grasslands pass through a period when the gross phenology changes rapidly. These gross phenological changes follow a distinctive pattern each year which is recognizable from one year to the next. Consequently, it is possible to designate a particular phenological pattern as a standard against which to gauge when the forage crop has reached "near-peak foliage development". At this time the grassland can be said to be at an "optimum photogenic stage".

(11) The term "optimum photogenic stage" refers to the fact that this is the best time to obtain aerial imagery for mapping dry forage on upland sites, characterized by shallow soils, and to

differentiate them from healthy green forage on sites characterized by deeper soil. These broad stratifications are particularly important in determining forage production because the difference in the amount of forage produced on these sites can vary by a ratio of about 9 to 1.

(12) The calendar date when the annual range in a given area reaches an "optimum photogenic stage", can be correlated with the amount of forage produced. Presumably, a late date for the optimum photogenic stage corresponds with a large amount of forage production, whereas earlier dates of occurrence presumably can be correlated with lesser forage production.

In order to demonstrate how the model might work let us take a hypothetical example within the California annual grassland range. Let us assume that, on the average, a rangeland area receives 20" of annual rainfall. Furthermore, let us assume that the average date of seed germination is November 1, and that the "optimum photogenic stage", corresponding to an average forage crop of 5000 pounds per acre, occurs on May 1. Finally, let us assume that the extremes of forage production are 8000 pounds per acre in the best year, and 2000 pounds per acre in the poorest year.

Now let us consider that we have a monitoring capability from a satellite system, such as ERTS-A, that will provide us with photographic coverage at frequent intervals during the autumn and spring of a given year. Several monitoring situations and predictions of production are presented:

Situation 1: On November 7, most of the grassland suddenly appears green, indicating that seed germination occurred about the first of November. Further monitoring shows that the "optimum photogenic stage" occurs on about May 1. Prediction: This is an average year, i.e., about 5000 pounds per acre.

Situation 2: The grassland still appears dry on November 7, and in fact it still appears dry until December 1. The optimum photogenic stage occurs on April 7, and the range is dry by May 1. Prediction: This is a below average year; how close the forage production figure approaches the 2000 pounds per acre figure will depend upon how close the date on which the "optimum photogenic stage" occurs corresponds to that of the poorest forage producing year.

Situation 3: On November 1, the range is already green and, in fact, earlier photography shows that it turned green early in October. By May 1, the crop is still green and in fact does not reach the "optimum photogenic stage" until June 1. Prediction: This is an above average year--approaching 8000 pounds per acre.

Obviously, a great many such situations are possible, each of which might be correlated with specific forage production curves. For example, the forage may germinate early, but mature according to an average crop in which case the prediction for forage produced would be slightly above average. Similarly, if the crop got off to a late start, but growth was prolonged due to favorable rainfall, the crop could still yield slightly above average amounts. On the other hand,



the crop could get off to a good early start, but because of inadequate rainfall, mature early and yield a below average crop.

In any of the above cases, the situation can be determined through analysis of the time of seed germination and the time that the "optimum photogenic stage" occurs. Other important inputs include (a) knowledge of the average forage crop for an area, (b) the magnitude of deviations from the average crop, and (c) the date when the average forage crop appears at an "optimum photogenic stage".

To apply the model up and down the state of California, one would need to know the average date when germination occurs and the average date when the "optimum photogenic stage" is reached in each geographical area or climatic zone. These dates will obviously be different from one climatic zone to another. For example the optimum photogenic stage may occur, on the average, between the first and middle of March in the 5" rainfall belt, where average forage production may be only 500 pounds per acre, plus-or-minus 100 pounds for good or bad years. In the 20" rainfall zone, the "optimum photogenic stage" for the average year may not occur until May 1 and the forage crop may be 5000 pounds per acre.

There is reference in the literature indicating that a high correlation exists between forage produced and average annual rainfall (between 5" and 15" of rainfall).<sup>\*</sup> Maximum forage production of annuals (reaching 8000 pounds per acre) occurs in the rainfall zone

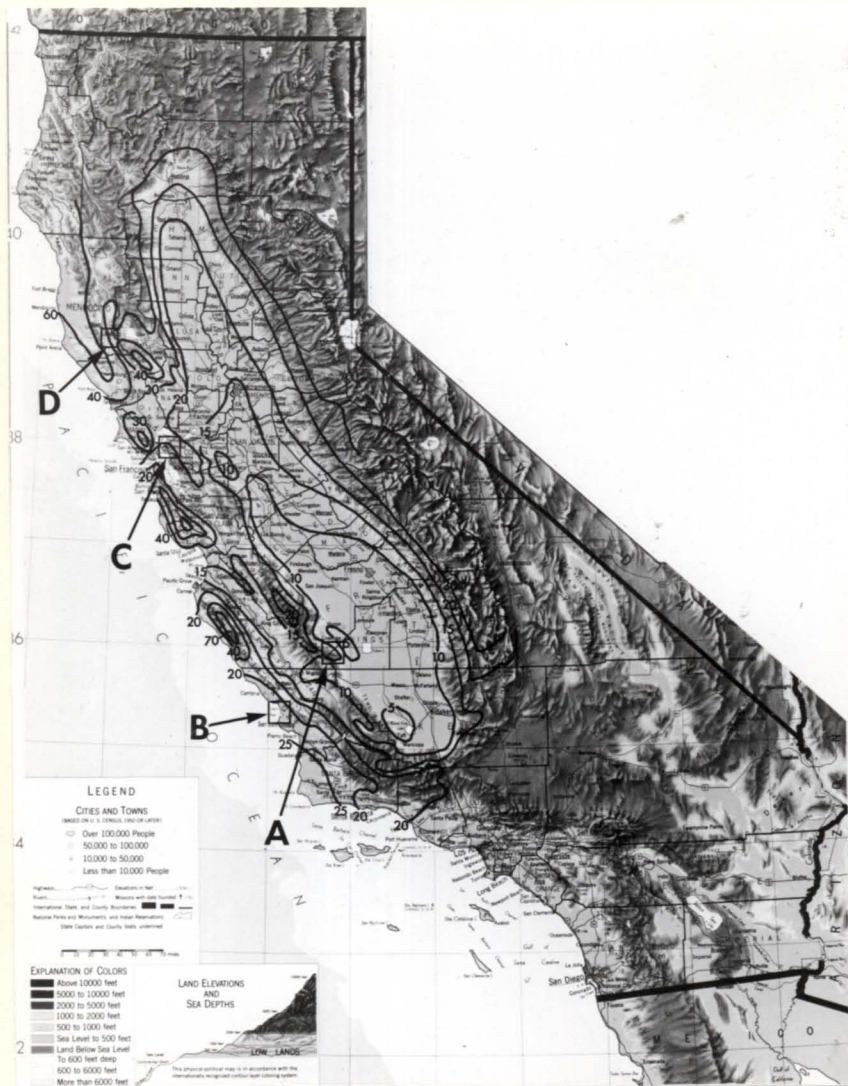
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<sup>\*</sup>Janes, E. B. 1969. Botanical composition and productivity in the California annual grassland in relation to rainfall. Masters Thesis. School of Forestry and Conservation. University of California. Berkeley.

receiving 20" to 25" of average annual rainfall, but areas receiving more rainfall generally have less than maximum forage production (around 4000 pounds per acre) because the cooler temperatures associated with high latitudes and elevations tend to inhibit growth.

Reference to the photographic illustrations (Figures 4.7 through 4.9) will help to visualize how interpretations made from small scale photography provide the needed information to make predictions regarding the amount of forage produced. Part A of Figure 4.8 shows an area around Coalinga, California. The rangeland area imaged in the photograph normally receives between 5 and 10 inches of annual rainfall. That portion of the rangeland area which receives only 5" is already dry, whereas most of the range that is associated with the 10" rainfall zone is at an "optimum photogenic stage". Because the amount of rainfall received prior to the time when the photographs were taken is below average, it is presumed that the forage production is well below average.

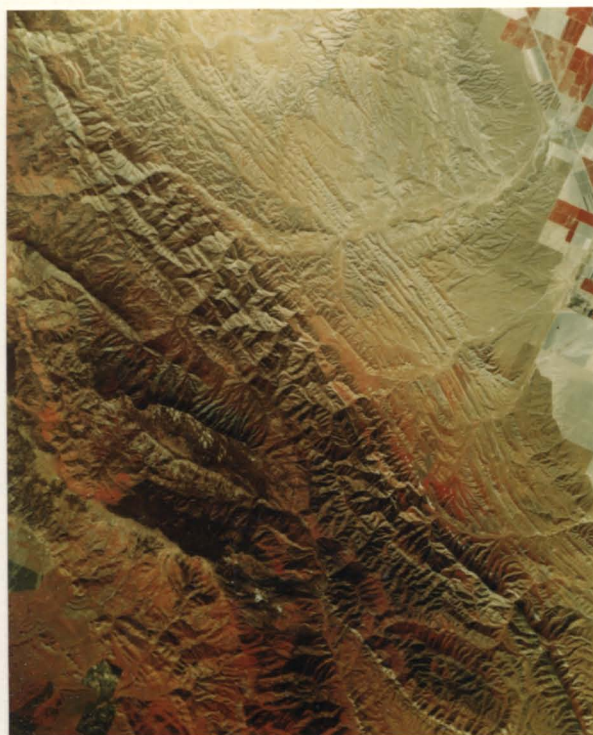
Part B of Figure 4.8 shows annual rangeland near San Luis Obispo. The range here is at nearly an "optimum photogenic stage" as is evident by the contrasts between the healthy and dry vegetation. However, the rainfall that had been received at that site during this particular year by the time when the photos were taken was well below the average. Therefore, it is presumed that the "optimum photogenic stage" is occurring much sooner than the average for that area. One can thus predict that the forage crop will be well below average.



NOT REPRODUCIBLE

Figure 4.7. Isohyet lines showing distribution of rainfall in inches per year have been indicated on this map of California. Examples of high-flight imagery, taken at points A through D in the spring of 1971, and showing grasslands which receive different amounts of rainfall are presented in Figures 4.8 and 4.9.





A.



B.

NOT REPRODUCIBLE

Figure 4.8. Examples of RB-57 high-flight photography taken over the central California Coastal Zone on April 2, 1971 showing: (A) Annual grassland south of Coalinga, California. Average annual rainfall ranges from 6" in the low lands to 10" in the foothills. The amount of rainfall at the date of photography was below normal for that date, thus below average forage yields are expected. Note that low land areas are already dry, while foothill sites are near "optimum photogenic stage". (B) Annual grassland near Morro Bay. Average annual rainfall in this area is about 22". However the rainfall received to date of photograph was 6" below normal to that date. The range appears to be at "optimum photogenic stage" but this is occurring much sooner than is expected. Hence below average forage yields would be predicted in this area.

Part C of Figure 4.9 shows an annual grassland area northeast of Berkeley, California. The forage here has not yet begun to dry. In fact, rainfall to the date of photography was slightly above average. It can be predicted that this range will produce a forage crop a little above average. This was confirmed by observations which indicated that the "optimum photogenic stage" was not reached until about 10 days beyond the predicted average time for "optimum photogenic stage" to occur for this area.

Part D of Figure 4.9 shows annual rangeland near Hopland, California. Average rainfall for this area is about 40". At the time when the high flight photos were taken it still appeared very green, and because rainfall to that date had been above average one could predict that forage production also would be above average. Further monitoring, on about May 10, would have been desirable to substantiate the predictions made about the forage crop yield near Berkeley and Hopland.

Admittedly, the model that has just been discussed is very simplified, when one considers that forage production is actually based upon complex interactions of the physical and biological environment. However, simple observations of time of seed germination and the time of "optimum photogenic stage" seem to be quite closely related to the amount of forage produced in a given area.

Although the prediction model may not apply with equal validity throughout the entire California annual grassland (20-25 million acres), it provides a starting point from which assessments of relative





C.



D.

NOT REPRODUCIBLE

Figure 4.9. Examples of RB-57 high-flight photography taken over the northern California Coastal Zone on March 31, 1971 showing:  
 (C) Annual rangeland east of Berkeley. Average annual rainfall in this area is about 20". The total seasonal rainfall received by the date of photograph was above normal. The rangeland has not yet reached "optimum photogenic stage", but because seasonal rainfall has been above normal a slightly above average forage crop can be predicted.  
 (D) Annual rangeland near Hopland. This area receives an average of 40" of rainfall each year. Rainfall to date is well above normal. One can postulate that the forage yield will be above average but it is as yet too early in the season to make a reliable prediction.

range condition and relative forage production can be made from area to area. The fact that rainfall is not equally distributed over the state, and that one geographical area can have a good forage year while another area has a relatively poor year, may be justification enough for a monitoring system which provides the regional coverage to make such assessments. What is needed in order for the model to be used efficiently is more ground information in the various geographical portions of the annual grassland range concerning the average yield of the forage crop and the deviation from this average as influenced by above or below average climatic conditions.

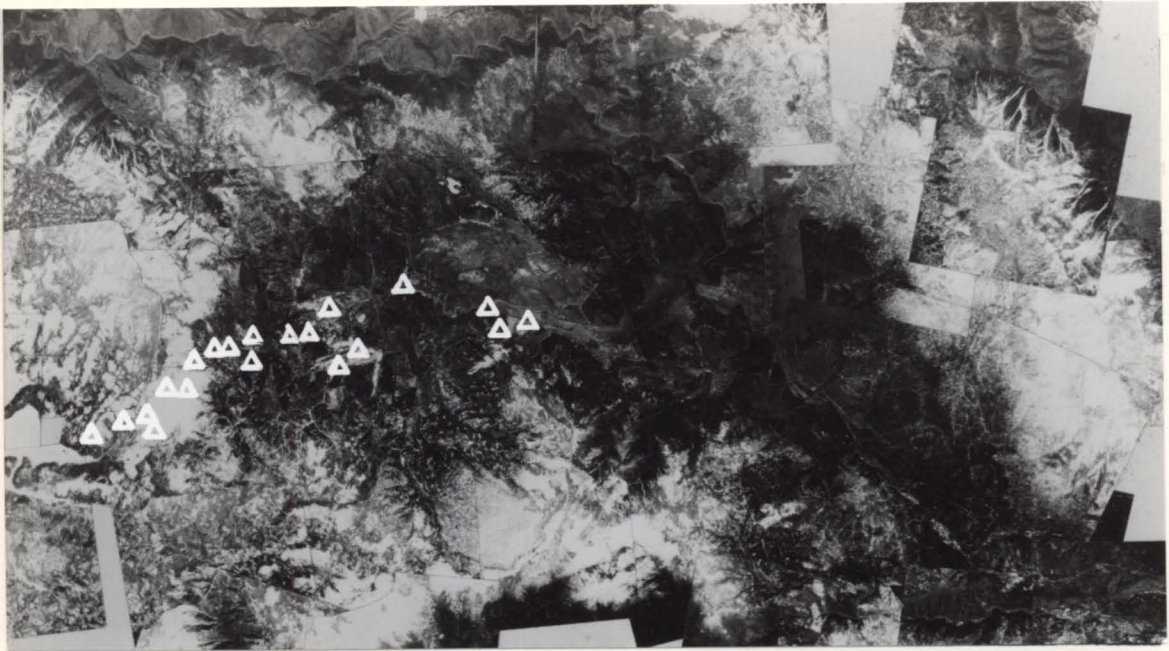
The information acquired about the development of the annual grassland crop has many applications. First, one can predict which areas may be over utilized because crops are below average, or under utilized because the existing number of cattle cannot possibly consume the above average crop of forage. Better information regarding expected crop yield could lead to better utilization of the crop. By predicting the length of the growing period, the rancher is in a more favorable position to know when to move his grazing animals to market to obtain the best price, or to determine how much additional hay he may need for supplemental feeding if he chooses to keep his cattle on the annual range. Producers of livestock feed could also benefit from this information. Finally, the rancher might also use this information to determine when it is best to move his grazing animals from the annual range to other kinds of pasture.

### Snow Surveys

During the winter and spring of 1971-1972, research will continue for purposes of developing optimum techniques for delineating snowpack on small scale, synoptic view imagery and for determining the accuracy with which snowpack boundaries can be mapped. Two primary phases of operation will take place in the coming months--ground data collection and image interpretation. (We assume that the U-2 high-flight imagery currently being procured on an 18 day cycle over the entire Feather River Watershed will soon be released for analysis.) Permanent snow survey ground plots have been established within the Bucks Lake Test Site and will be visited each time high altitude imagery is acquired over the area. These plots have been located purposely at different elevations, on steep to moderate slopes, on several different aspects and under different types and conditions of vegetative cover. Personnel with the Snow Surveys and Water Supply Forecasting Section, Department of Water Resources, State of California, have cordially offered to the FRSL use of two Mount Rose snow sampling tube sets. This equipment will allow our field crews, traveling by snow mobiles when necessary, to measure snow depth, snow condition and water content at each permanent plot. The photo examples in Figures 4.10 and 4.11 show the locations of these permanent plots, and also, the appearance of each plot seen on small scale imagery taken in March and June, 1971. Furthermore, during each high-flight mission, a FRSL crew will obtain low altitude oblique aerial

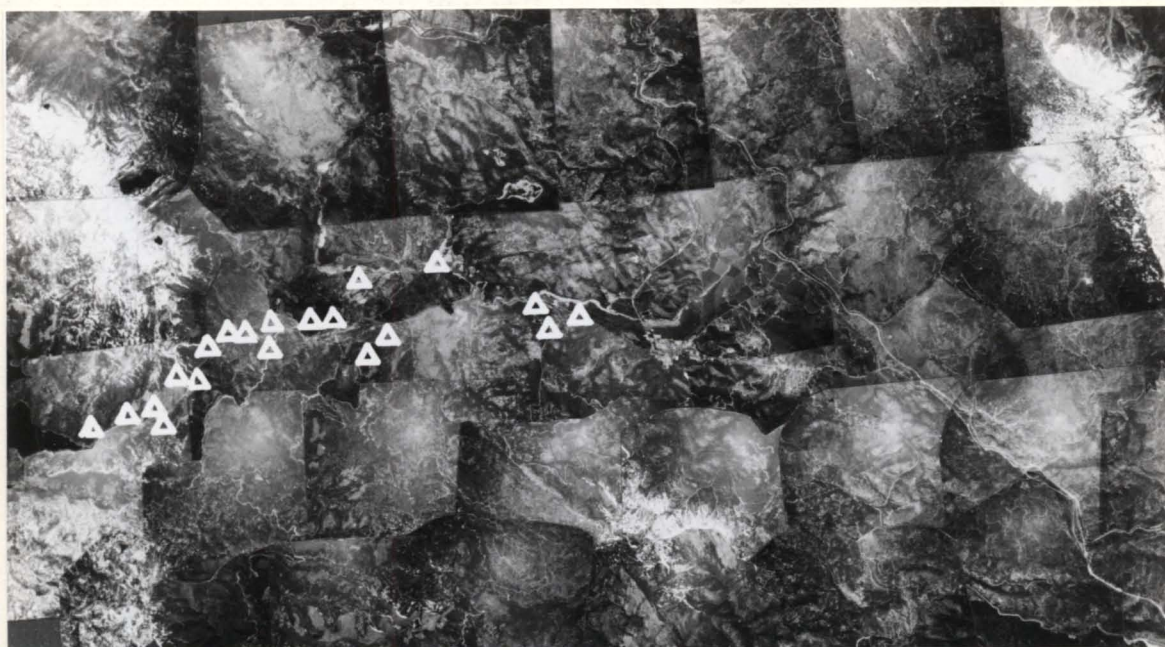


NOT REPRODUCIBLE



**Figure 4.10.** Permanent snow survey ground data plots have been located in areas considered to be reasonably accessible during the winter months. The plots represent a variety of topographic and vegetation/terrain conditions, and they will be visited each time a U-2 high-flight photographic mission occurs. By studying this example (March 1971) and the example shown in **Figure 4.11** (June 1971), the appearance of each plot in terms of snow conditions can be compared when seen on imagery taken at two different dates.

NOT REPRODUCIBLE



**Figure 4.11.** The appearance of each permanent ground plot, in terms of snow conditions, can be seen here on imagery taken on June 14, 1971. Compare this illustration with the previous example -- which shows the same area as imaged on March 17, 1971.

photographs (black-and-white polaroid pictures) of numerous snowpack boundary conditions which may not necessarily be associated with any of the permanent plots. And, if time permits, transects will be run on the ground the following day across these boundaries. For that operation the oblique photos will be used to navigate from one ground point to another. Snow depth and vegetation/terrain conditions will be recorded along these transects.

After a sufficient amount of ground data has been collected, training aids will be compiled which will illustrate, as clearly as possible, the influence of elevation, slope, aspect and vegetation/terrain type on the image characteristics of snowpack conditions and boundaries. Possibly one of the first requirements during this study will be to define exactly what is a "snow boundary" or "snow boundary condition"; however, both high altitude imagery and ground data must be studied even before this decision can be made. In addition, a close working relationship with members of the California Department of Water Resources and researchers within the U.S. Forest Service will continue to be maintained as we progress with this work.

In addition, the data collected from (1) the permanent ground plots, (2) the low altitude aerial oblique photographs, and (3) the ground transects will be useful as we attempt to quantify the accuracy levels associated with snow boundaries mapped through various topographic and vegetation/terrain conditions.

### Environmental Change Surveys

The study of environmental change that has been completed for 150,000 acres, using photo index sheets dating back to 1941, has allowed us to (1) become familiar with the image characteristics for a variety of man-made and natural landscape changes, (2) train personnel to detect and identify these changes, and (3) map these changes during five different periods over the 29 year interval. In addition, ground data on changes currently taking place within Bucks Lake test site are being collected by FRSL staff members in the field and from public and private sources--particularly, timber harvest, brush field manipulation and forest fire data. No further interpretation is planned until imagery from U-2 high flights and/or from orbital vehicles (i.e., ERTS-A and Skylab) is procured over the study site and made available for purposes of analysis. At that time, low resolution, synoptic view imagery acquired at two times, with a one-year interval between missions, will be analyzed using the techniques discussed above. Thus, once the interpretation task has been performed and results compiled on map-sheet overlays (or possibly transferred to planimetric base maps), the interpretation data can be correlated with ground data, particularly in the case of forest cutting patterns, cleared brush fields and fire scarred areas, and evaluated in terms of level of accuracy.

### Summary

Hopefully, the work being performed by personnel of the II&E Unit, along with the findings of other staff members of the FRSL, will result

in our developing sound resource inventory techniques applicable to enormous land areas. We feel that the key to a successful input to this project from our group lies in being able to demonstrate that meaningful regional vegetation/terrain, snow and environmental change surveys can be performed rapidly with the aid of synoptic view remote sensing imagery.

#### 4.4 REPORT OF THE AUTOMATIC IMAGE CLASSIFICATION AND DATA PROCESSING UNIT

The primary function of this unit, as part of the Laboratory's overall image analysis capability, is to study techniques which utilize data processing equipment as a means of extracting useful information from remote sensing imagery. The emphasis is upon information, not just data extraction, because often the ability to generate data from pictorial or taped records is not always a clear indication that successful information of use to, say, the vegetation resource manager will be forthcoming. Data processing alone is insufficient if operational procedures are to be developed and demonstrated for land surveys and resource analyses. Thus, our specific activities have stressed the derivation of "information" through automated and semi-automated digital processing techniques. The FRSL Terminal/Display system has been designed to facilitate the process of reducing data in a variety of formats to a digestible state for producing useful resource information. With the total efforts of the FRSL directed towards both manual and automatic feature identification and classification, it is

easy to see that we are ideally suited to examine and define an effective interface between man and machine insofar as vegetation resource analysis is concerned.

In addition, the current status of the Terminal/Display system is such that utilization by other participants in the study is a factor which governs our approach towards software development. It is planned that non-FRSL personnel will have occasion to conduct studies with the aid of the Terminal/Display system. Much of the discussion of the current state of development of this facility is aimed at describing its flexibility and versatility for a wide variety of applications. A glance at the components which make up this facility readily indicates its diverse input/output configuration which enables thorough digital processing from both a feature classification and a feature enhancement standpoint (since these two processing functions are clearly inter-related). Both techniques of image processing are reported upon as part of our study activities in resource analysis.

It seems appropriate for this second year's Progress Report to document in some detail the status of all aspects of our image classification and data processing activities as they relate to the primary objectives of this study. We have certainly reached a stage of development whereby the product of our "system" definition--namely, the FRSL Terminal/Display facility--enables us to conduct "R&D" applications studies which combine the best attributes of manual and automated data interpretation techniques. But our energies have not been directed solely towards "equipment development." As we reported in



our first annual summary of activities, several areas of future research were clearly evident. We have made significant progress toward the effective utilization of image processing (feature classification and enhancement) techniques through the Terminal/Display system and have developed a computer-oriented storage and retrieval capability ("data bank") for use by the resource manager. The current status of these activities is described in the present progress report.

#### 4.4.1 Work Performed During the Period Covered by This Report

Much of our effort during this reporting period has directly involved systems development leading to the current status of our FRSL Terminal/Display facility which is next described. However, considerable discussion is also presented concerning our current and future intended use of the facility as a research tool for the logical development of operational techniques in resource analysis.

##### FRSL Terminal/Display System Status.

A review of last year's Annual Report indicates that the system contained the following components:

- . a process control "mini-computer" with 8K words of memory
- . a cassette tape recorder for special local applications
- . a prototype scanning microdensitometer
- . a keyboard and teletype with I/O capabilities
- . a data link to nearby CDC6400 computer center facilities
- . a 9-track industry-compatible magnetic tape drive
- . a storage tube CRT device for display and graphics

As of this writing, we have added the following components as per our original ADP equipment proposal documentation for this study:

- . components for 1/3 of our color display subsystem (these include a Hughes Model 639 Scan Conversion Memory device and a 19" color monitor)
- . a small digital disc for high speed data (pictorial) manipulation
- . a graphics "joystick" controller
- . a high-speed paper tape handling capability (read and punch)
- . a hard copy unit for recording images derived from the CRT screen

Additionally, under separate funding sources, we have incorporated several components designed to facilitate the system's versatility. These include an updated scanning capability for our microdensitometer, an additional 9-track tape unit for tape-to-tape data manipulation, and a punched card reader. These additional components (and modifications to original devices) are described subsequently. Figure 4.12 contains a current schematic of the total FRSL Terminal/Display configuration which can be compared with Figure 4.8 of last year's report. All of the components of the system that are presented in Figure 4.12 are briefly described next. Detailed schematics and interface logic for each are available but they contribute very little to this presentation, since the user of such a facility is primarily interested in what the peripherals can do for him and how reliably these functions can be performed. It is in this context that



# FRSL TERMINAL/DISPLAY

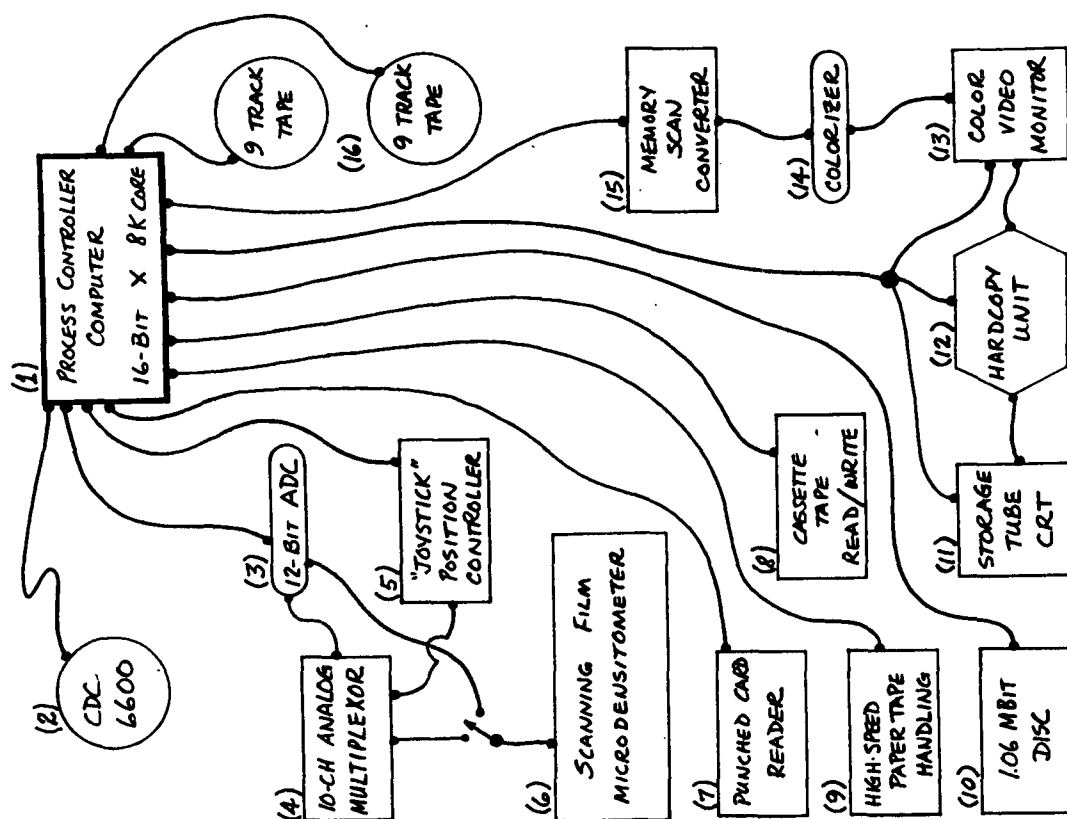


Figure 4.12. FRSL Terminal/Display System. The schematic at the left shows the inter-relationships of the various system components. The heart of the system is the "Process Controller" computer. Each device is designated by a parenthetical reference number which corresponds to its description in the text. For comparison purposes, this figure may be viewed in light of last year's system-status schematic, Figure 4.8.

component descriptions are presented. In each case of component specification and selection, utmost care has been taken to obtain the best device for the money invested to insure that our overall data processing and image analysis objectives would be met.

A. Hardware

The components are described and referenced by number to those appearing in Figure 4.12.

(1) Process control computer; this device is essentially as described previously, a 16-bit word length "mini-computer" possessing 8K words of core memory. All interfacing of peripheral devices which the computer controls is done "in-house" with the exception of the disc controller.

(2) Communication link to a large high-speed general purpose computer; our line-of-sight device for transmitting data between stations is currently suspended as a developmental activity in favor of the more conventional phone line hookup between stations. Our line-of-sight device is about 80% complete and will be fairly easy to return to in the future as time permits. We had originally planned to link up to a CDC6400 general purpose computer but for a number of reasons it appeared in the best interests of the government for us to abandon this initial effort because of time delays and inadequate support facilities, especially core storage facilities. In the last few months we have implemented a new and (we feel) more logical link-up at a different facility possessing greatly

reduced cost to our projects as well as adequate support services for our requirements. This line is to a very large high-speed CDC6600 computer. Our transmission rates are currently 4800 baud but with improved circuit analysis we expect to at least double this rate. This will enable us to fully utilize the power of the larger computer for our studies. This line is essential of course to our requirements for a large computational capability for multiband tone signature and texture analyses. We have a modified version of the LARS pattern recognition routines presently operating on the CDC6600. Since the closed-shop general purpose computer is unsuitable to an effective man-machine interaction for interim decision making, some sort of facility for gaining access to the processing operation is necessary. This is accomplished through a remote terminal facility whereby we can transmit partial operations to our FRSL station for CRT display and decision-making prior to continuing the classification programs, without requiring a dedicated project computer at prohibitive expense.

(3) 12-bit analog-to-digital converter. This was part of the system last year but has not been described in any detail. It allows us to digitize an analog signal, such as the one obtainable from the scanning microdensitometer, for subsequent processing.

(4) 10-channel analog multiplexor. This also was a part of last year's system configuration but was not described in any detail. It allows us to "enable" up to ten analog signals from various devices which can then be singly selected via computer control,

depending on the processing objective. For instance, it is used for the potentiometric decoding of the X and Y positions of the "joystick" device described next.

(5) "Joystick" position controller. This console device has a computer-decodable position analysis and pushbutton function generator. The controller is used to locate or select data from some logical output device (usually one of the CRT devices). It will ultimately be used in general graphical applications. It also will be used for training sample selection of coded imagery for transmission of coordinates in connection with our pattern recognition routines.

(6) Scanning film microdensitometer. This is roughly the same device as was described in last year's report, but with the modifications proposed therein now implemented. A commercial movable stage was purchased to upgrade the positioning accuracy. Improved circuitry was also included in this new version such that sampling frequency for film densities could be as rapid as 2000/second, a ten-fold increase over the old system. We have also improved the light source to 1000 watts intensity giving us increased sensitivity at the darker densities and also yielding a more desirable color temperature for density analysis work. Apertures are estimated to be about 20 microns.

(7) Punched card reader. Our 400 card per minute reader is now an integral part of the system as an input device. The hand-marked reader option which we originally requested was found to be unreliable

and was taken off the market by its manufacturer for further development.

(8) Cassette tape read-write device. This device is essentially as described in last year's report. An additional "read only" cassette device has been added for use in conjunction with our FRSL ground data collection system, described elsewhere in this report.

(9) High-speed paper tape handling. Both paper tape reading (300 characters per second) and paper tape punching facilities have been implemented on the system during the past year. These facilitate principally the assembly and recording of programming routines for local station operation.

(10) 1.06 Mbit disc. This device has just recently been added to the system and, as described previously, will function as a high-speed image storage device as well as "interim" data manipulation and storage facility during operation of the pattern recognition programs using the transmission links.

(11) Storage tube CRT. This is unchanged from last year's description. Up to 800,000 addressable coordinates can be referenced on the screen, which makes it a high resolution device for pictorial and graphics applications.

(12) Hardcopy unit. This device was added as a means of providing "hardcopy" printouts of the material contained on the storage tube screen. Several of the illustrative examples included in the illustration section of our present report are copies made from this device.

(13) Color video monitor. An additional output device is our color monitor which works in conjunction with some of the other peripherals. This particular device was originally proposed to be used in a multi-image subsystem as the primary display unit. As of this printing we have only implemented a single channel configuration. We have described the complete three channel subsystem in our "Proposed Future Research" section. The complete color display subsystem is unchanged from our original proposal. The hardcopy unit will be modified in order to reproduce pictorial information from the face of the color monitor as well as it now performs this operation on the storage tube CRT.

(14) Colorizer. This special unit is used in conjunction with the closed circuit video subsystem for adding colors to linearly sliced density information (greylevels) detected by a conventional video camera. Six levels are sliced with three or more slices being assigned a discrete color code for display purposes. We will soon have on a "loan" basis, at no cost to the project, a new sophisticated video signal processor device from a firm in Lawrence, Kansas, which will greatly enhance our image analysis functional repertoire. This device is superior to any "density slice" equipment now on the market because it does not restrict users to linear density slices and it offers a number of other important functional processing options.

(15) Memory scan converter. This is an additional special device that is used in conjunction with our originally prescribed color display subsystem. The unit serves as an interim read/write storage

memory under computer control with subsequent readout to the color CRT monitor for display.

(16) Two nine-track magnetic tape drives. During the past year an additional tape drive was added and both controllers implemented to be industry-compatible. Tape-to-tape and duplication routines are available for outside users possessing nine-track computing capability. Also, this configuration is ideal for ERTS digital tape formats and our own computer word length specifications.

#### B. Software

Along with our hardware development efforts there logically must be software support to enable effective use of such equipment. Here, our activities have been structured in a way which would permit us to move ahead in several areas of application with the ultimate objective of bringing all aspects of our software in common register with the terminal transmission capability of the Terminal/Display facility. These application areas are: (a) pattern recognition (spectral response) analyses of multichannel sensor data, (b) texture (spatial frequency) analyses of various scales of sensor imagery, (c) optical density analyses, (d) analyses of computer-generated graphics for mapping and feature delineation, and (e) development of data storage and retrieval techniques. We have devoted considerable effort to each of these areas of application, as the illustrations section reveals, because they are critical factors in keeping pace with requirements for data processing and data manipulation as imposed

by the potential users of such techniques. Also, these feature classification and enhancement topics are directly applicable to our progression from the analysis of sensor data obtained from high altitude aircraft to the analysis of ERTS-A satellite sensor data.

Briefly, the capabilities provided by our current software package in each of the areas mentioned are described next. We are working on a "User's Manual" which will describe the total capability of our system from the user's viewpoint. We will incorporate the ideas and suggestions of skilled image interpreters in the development of this manual in order to insure proper conceptual balance between natural science and engineering science. Our Laboratory structure places us in an ideal position to implement an effective interface between manual image processing techniques and automated techniques.

(a) Multichannel pattern recognition routines. As mentioned in our first year's report, it is not the purpose of our activities to duplicate hardware or software developed at other institutions, since this is neither in the best interests of NASA nor consistent with our overall study objectives under which we seek to use limited funds to best advantage in carrying out our various tasks. Rather, we have been successful in adapting certain software routines to our particular computer facilities instead of rewriting them completely. We have done this with the automatic pattern recognition programs developed at the Laboratory for Applications of Remote Sensing (Purdue). These routines enable man-machine interaction in the automatic recognition of spectral



information recorded in as many as twelve channels of sensor data. These routines have been adapted to the CDC6600 computer at the Lawrence Berkeley Laboratory and some results of spectral analysis utilizing our version are described in a later section.

Ultimately, this technique will be upgraded to enable the interaction of the full capability of our Terminal/Display facility. Presently, we scan the optical densities in multichannel photography (or we may scan, as an alternative procedure, multi-date photography) and transmit these data successively to LBL for pre-processing of a greylevel map for the selection of training samples. From such samples we can define the spectral properties of features we wish to automatically recognize elsewhere in the imagery. Our plan is to complete our software to the extent that initial scan and display can occur at our local station. In this way we can implement the joystick device for the selection of training samples to transmit to the LBL for final processing. Some examples of our local station scan and display are included in the illustrations section.

Not all pattern recognition and feature enhancement operations need be conducted through a linkage to the LBL computer facilities. One of the real strengths of the system we have implemented is its reliance upon large computer interaction only when it is required. Our local station data manipulation capability, while quite modest in comparison to the LBL facilities, easily accommodates single-image density slice and display routines for isolating particular features of interest in a scene. Figures 4.13 and 4.14 show digital density

slicing for feature enhancement and classification. Some subsequent figures illustrate the same technique using the color monitor for display purposes.

(b) Texture analysis routines. In addition to the information which can be extracted from a point-by-point classification of spectral responses recorded on sensor imagery, considerable use can be made of the textural, or spatial frequency, component of this same recorded signal. Thus, it is useful to consider not only the "spectral signature" analysis technique just mentioned but also the "textural signature" analysis which is to be described. The applications section describes specifics of some studies currently being conducted using texture as a correlative parameter in the information extraction process leading to improved image interpretation performance. Basically, the technique involves the scanning of various spatially distributed features (such as forest stands of different densities) with the use of a locally run transform routine based upon a one-dimensional Hadamard transform algorithm. The Hadamard transform was chosen because of its low computational cost (compared to other transform routines) and its ease of operation within our system components. The routine generates a series of "digital masks" of increasing periodicity and causes these masks to shift regularly and sequentially in relation to the scanned image, thus producing a series of energy coefficients. The minimum, maximum, and mean energy coefficients are computed for each scan line and averaged over several scan lines within data of "homogenous" spatial frequency properties (as may be determined by an interpreter in conventional timber typing operations

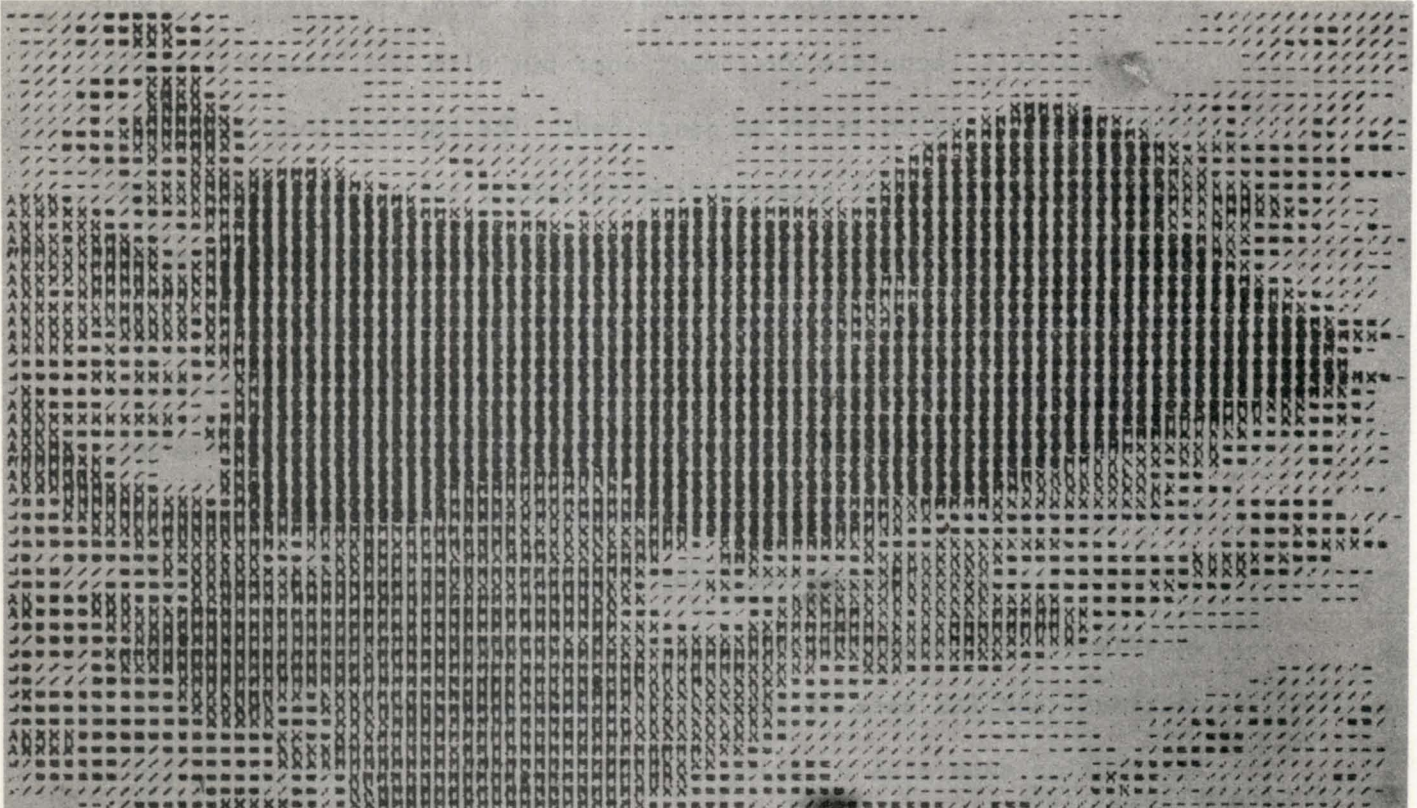
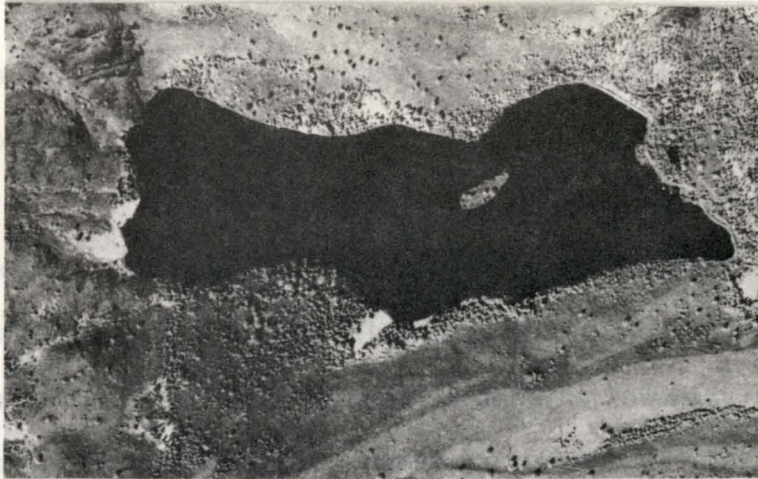


Figure 4.13. Digital density slicing and display capabilities are demonstrated above. The photo at the top is a print (enlarged 25x) of the negative scanned and displayed in eight density levels. Any number of "slices" can be viewed as a preprocessing procedure. Eight are shown here for illustration purposes. Areas represented by slices are readily available as a percent of total area sampled.

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Figure 4.14. Part of the area shown in this figure is snow-covered. Snow vs. "everything else" is depicted in this illustration. A comparison with the original photograph from which this display was derived indicates excellent results for the detection of "SNOW" when it is not obscured by tree shadows. The light toned symbols above denote snow; some of the darker symbols appearing within the snow boundary are commission errors caused by scattered tree shadows (about 5%). Otherwise, as expected, the technique of using a microdensitometer to detect and subsequently enhance through digital processing a feature such as snow proved very successful.



on aerial photography). Finally, these coefficients are correlated with other data derived from the areas of interest, as described in later examples. Preliminary results using this procedure with forest stand densities show high correlations with many of the parameters used in making cutting and forest management decisions.

(c) Optical density feature extraction studies. These digital techniques have already been mentioned earlier. They involve use of the scanning microdensitometer in conjunction with the storage tube display and one of the data storage devices (magnetic tape or disk). An image is scanned under direction of the user who places dimensional parameters defining his area of interest. Upon completion of the scan, a computer generated histogram is displayed on the storage tube for inspection by the user. This histogram consists of the frequency distribution of density values recorded through the a/d converter electronics. Often peaks and valleys appear in the histogram suggesting suitable "slices" which define homogenous density levels. Up to eight slices can mechanically be selected by the user with the joystick as a pointer device. Following slicing, the computer generates a pictorial map with symbols assigned to each sliced level for viewing purposes. With some data (imagery), it is possible to isolate, or enhance, features directly with this procedure. Of course, once a useful slice has been made in the digital data, it is an easy process to derive the area represented by the slices. Thus, in a relatively few and easily understood processes, it is possible to derive information from considerable amounts of data. The reader is referred to

Figures 4.13 and 4.14 for examples of digital density slicing operations.

(d) Graphics for mapping and feature delineation. A package of software routines has been developed for use with the storage tube display and the color CRT monitor. These routines enable the user to generate alphanumerics and vectors, and to plot in a point mode. All of these capabilities are useful attributes for a computer controlled graphics system. These routines utilize the joystick device and the CRT's. Examples of graphics were presented in last year's report and no further examples will be presented at this time. It should be fairly easy to see the potential application of the graphics capability to that which has already been herein discussed. Training sample selection, feature selection and display (enhancement), mapping of information directly upon scanned data, automatic transfer of ground truth data to digital maps for coding purposes, mapping coordinate generator, and many more applications are possible with the addition of the graphics capability.

(e) Data storage and retrieval techniques. Our data bank storage and retrieval system has evolved to its present status during the past year. The system is called MAPIT and is essentially operational from the user's viewpoint. As with all data bank systems, the most time consuming aspect of its development stems from time required for the assimilation and reduction of source material for digestion by the computer into what we call profiles or maps. The following is a brief discussion of MAPIT. Examples of applications are discussed in a subsequent section.

MAPIT consists of a package of FRSL computer subroutines providing for the efficient storage, retrieval and updating of one or more profiles of resource data. It is written in FORTRAN IV and COMPASS and was developed for use on the CDC 6600 computer at the Lawrence Berkeley Laboratory. The routines are comprised of several mapping systems which are commonly used in practice today, with the best features of each being incorporated into our version in order to facilitate the handling of a more diverse set of input profiles. MAPIT relies heavily upon the usage of mass storage devices (i.e., disc, drum, magnetic tape, etc.).

A "profile" is the result of translating triplets of data into spatially oriented X-Y pairs through conventional coordinate reference and an associated "Z" value. For example, the topographic map conforms to this set of requirements by a translation of XYZ triplets (i.e., longitude, latitude and elevation) into XY pairs with the Z value coded as a contour interval. Many maps also have additional information superimposed upon these three elements, such that Z can be thought of as an open-ended population of sub-elements,  $(Z_1, Z_2, \dots, Z_n)$ , each of which denotes a different "attribute" or condition associated with its respective XY pair. By virtue of this configuration, it is fairly easy to represent three dimensional data in two dimensions. And due to the manipulative characteristics inherently associated with MAPIT's subroutines, it is also fairly easy (and often desirable) to not only "take a look" at particular stored profiles in their original state, but also to create "new" data files through the combi-

nation and correlation of existing profiles.

MAPIT was conceived to operate with data whose X and Y coordinates serve to reference a particular point on the ground and whose Z represents a particular attribute or condition at that point. Thus, MAPIT is particularly well-suited for use with data from maps, photographs and related remote sensing imagery and true ground annotations. Conceptually, then, MAPIT consists of a box with particular width, length and height parameters, any element of which can be absolutely referenced by the appropriate XYZ triplet data point. Each Z profile is itself a map of the condition or attribute at that particular height within the box, as depicted in Figure 4.15.

How MAPIT Works: MAPIT takes an area which is defined by the user and divides it into "cells". The shape of each cell and the area it represents in true ground equivalence is a function of (1) the resolution in both the X and Y directions of the device which will display the map, (2) the scales in both the X and Y directions at which the area is to be mapped, and (3) the dimensions in the X and Y directions of the area itself.

For a given display device, the area represented by each cell (which in turn is represented by a single symbol on the device) can be treated in one of two ways, keeping in mind the following formula:

$$\text{Area} = \frac{\text{RFD}(X) \cdot \text{RFD}(Y)}{\text{RES}(X) \cdot \text{RES}(Y)}, \text{ where}$$

RFD = the representative fraction denominator (1/scale)

RES = the resolution of the display device (divisions/units of linear measure).



## DATA BANK CONFIGURATION

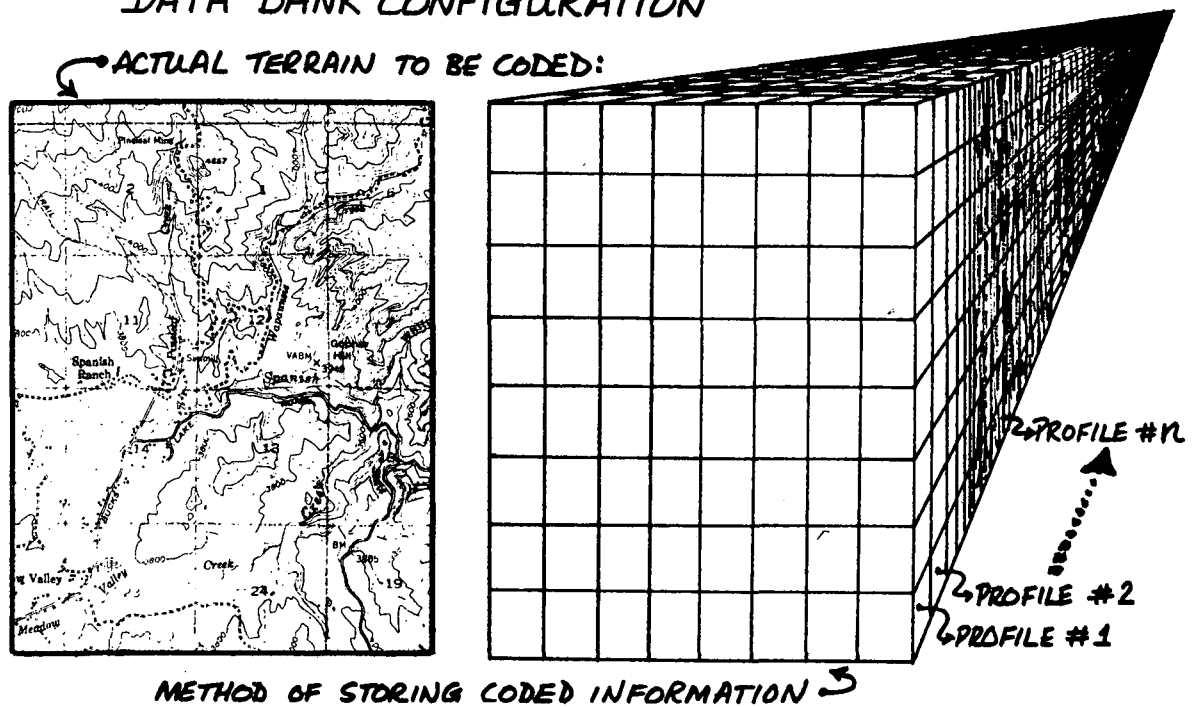


Figure 4.15 FRSL "data bank" configuration. Shown above, in a highly simplified schematic, is our conceptual approach to storing and retrieving information about an area of interest. In this case, a portion of the NASA Bucks Lake Forestry Test Site in Northern California is shown for illustrative purposes. The data bank is a three dimensional array of data points with X and Y coordinates representing ground location points. The Z coordinates consist of "profiles" of discrete types of information which currently reside in our FRSL data bank are data about vegetation types, forest fire history, cutting history, land-use activity, zoning classifications, geologic types, etc. The amount of profile information which can be stacked on the X and Y scales is virtually unlimited; however, in terms of computer processing time for data extraction, it behooves the user to maintain useful profiles, calling out data which have become outdated or which might be better replaced by alternative data. Access to the data bank is by reference to the particular profile addresses. It is a fairly simple matter to extract information from the data bank which has been compiled from several discrete profiles. This is demonstrated in Figures 4.23 through 4.31.

The first method is to make a map with particular X and Y scales, allowing MAPIT to compute the area represented by each cell. This method allows the user to make a map at a desired scale and produces such a map with the greatest possible resolution on the display device.

The second method is to keep the area represented at some desired value, manipulating the X and Y scales to attain the desired result. This method may result in the use of odd-ball scales and an odd-ball sized map, but the map will have only the area resolution specified by the user. MAPIT works well with either method.

After the cell size is selected, the total number of cells in the map is determined. The user specifies a series of Z values which he wants mapped, as well as the number of smaller subseries, or slices, into which he wants any larger set divided. MAPIT then assigns to each slice an integer code, ranging from 1 to NL, where NL = the number of slices. (Zero is reserved for the special use of representing background values.) MAPIT then determines the minimum number of bits (binary digits) needed to represent, in memory, the entire range of codes.  $NBITS = \text{Log}(NL+1)/\text{Log}(2)$  and is rounded upward if it is not an integer value. For instance, if NL = 3, then NBITS = 2; and if NL = 6, then NBITS = 3.

If MAPIT were to assign to each cell of a map its own word of memory, this computer mapping process would be quite simple. However, since a computer word in the CDC 6600 contains 60 bits, it is quite obvious that when NBITS is considerably less than 60, a terrible

waste of memory results. Also, NBITS cannot be greater than 60.

For example, NL = 127 (a sizeable number of slices) yields NBITS = 7 and 53 bits of each word are left empty and wasted. For there to be no waste, NL would have to equal  $2^{60}-1$ , or more than 1 billion billion! Such a situation is extremely unlikely.

To solve this problem of waste, MAPIT packs each word with as many cells or fractions of cells as necessary to completely fill each word. The last word may or may not be completely filled, depending on the total number of cells. Suppose a map were 100 cells by 100 cells, or 10000 total cells, and NBITS = 9. The inefficient storage method would require 10000 words of memory. MAPIT, on the other hand, requires only:

$$\frac{10000 \text{ cells} \times 9 \text{ bits per word}}{60 \text{ bits per word}} = 1500 \text{ words}$$

and there are 6-2/3 cells per CDC word, a considerable savings.

MAPIT can accept data in two forms--gridded or digitized. Gridded data are obtained by placing a grid on the input source map, dividing it into cells just as MAPIT would. Each cell is coded, which can be done either manually or automatically. These codes are then transferred to MAPIT sequentially, one row after another. Only the codes (Z values) are needed because MAPIT generates the X and Y coordinates it needs. This option can be used quite well with scanned photographs. Digitized data consist of strings of one or more XY pairs, each string having an associated Z value. A string can represent single points, linear objects (roads, trails, boundaries, etc.) or patches on the source map. For single points, MAPIT codes only the cell into which

the data point falls. MAPIT treats linear objects by first mapping the data points and then interpolating, linearly, coding the cells lying on the line segment between each successive pair of points. A patch is mapped by first mapping its string, which is actually its perimeter, producing a closed boundary, then all cells within this boundary are coded.

Display is a simple matter of associating a particular symbol on the display device with a particular code.

Since MAPIT is only a package of subroutines, it is necessary for the user to write a mainline program. This program need only dimension the variables used by MAPIT, but it can also do anything else the user wishes. It is this feature which allows MAPIT to have no restrictions on the maximum numbers of data points, maps, slices, etc.

Input and Output: MAPIT has two phases--input and output. The input phase places a map in memory. The output phase produces a copy of this map. There are three modes to the input phase--create, read and collate. Create, as one might expect, causes a new map to be produced "from scratch" and places it in memory. Read transposes a previously created map from a mass storage device and places it in memory. Collate is more complicated. It reads one or more maps, each from a separate mass storage device, 100 words at a time, combining the information on these maps through a subroutine which the user must write to fit his own needs. The resulting "new" map is then placed in memory.

The output phase has two modes--storage and display. Storage takes a map, or any portion of it, and stores it in binary form on a mass storage device. Display copies any or all of a map and converts it to a form suitable for display. At no time does MAPIT have more than one map in memory.

Through proper manipulation of the options available, MAPIT can:

- . Create a map from scratch,
- . Store "permanently" all or any portion of a map,
- . Retrieve a previously stored map,
- . Manipulate all or any portion of one or more maps using a filtering or combination subroutine written by the user,
- . Update or correct a map, and
- . Display any or all of a map.

The time required for any particular problem is, of course, machine-dependent and a function of the complexity of the problem. However, to get a general idea of the time involved in using MAPIT, the following times are presented. It should be kept in mind that these are only rough figures, based on our use of the program to date.

- . Compilation of the source deck.....4-5 sec
- . Creation of a new map.....1.5 sec/10000 cells
- . Storing a map on magnetic tape.....0.006 sec/10000 cells
- . Collating 3 maps.....1.7 sec/10000 cells
- . Printing (Display).....1 sec/10000 cells/overprint

### User Oriented and R & D Applications with the FRSL Terminal/Display.

The current state of development of the Terminal/Display facility has enabled a number of interesting and relevant studies to be performed during the past year. Some of these studies are incomplete, but they are presented here as an indication of the level of interest and potential utility generated by our NASA sponsored efforts in developing such a facility. Several of the "outside" uses of our film emulsion digitizing facilities were made by graduate students doing experimental studies leading to doctoral degrees. One such study was conducted by a graduate student in Electrical Engineering whereby he was investigating the power spectra obtained from scanned aerial photographs of the spatial distribution of forest plantations. The study was terminated as the student was abruptly transferred from our Berkeley campus to work with the image processing staff at the University of Southern California. His efforts paralleled in some degree those in which we are currently engaged, as described in a subsequent section of this report. We are continuing our investigations of "signal variation" as an indicator of "texture" for the purpose of deriving statistics which can be correlated with known ground conditions. Some results of this work are reported upon later in this section.

A second study of this type was conducted (and completed) by a doctoral candidate in the Sanitary Engineering department of the Engineering School of our campus. Here the objective was to develop an improved technique for measuring the dispersion rates of dyes when injected into artificial channels analogous to those found in

estuaries. The technique used was one which incorporated precision photography and film density extraction. Tides in the channel were simulated and dyes injected at various tidal states in order that sequential images could be taken of the state of the channel, and hence the rate of dye dispersion. The next step is that of relating the findings to actual estuaries in order to improve the methodology of monitoring pollution spills and spreads through the use of remote sensing data. This is planned as part of the laboratory's projected plans in the coming year and is included in our "Proposed Future Research" section.

Several other examples of outside use could be mentioned but the two cases just cited are most relevant to our own internal research studies. Examples of "output" from the first study are presented in the illustration section of this report.

Use of the system for research purposes consists of many varied applications, depending on the components specified. The system is configured such that image processing can be performed directly from either digital tape inputs or digitally reduced images, through scanning procedures. In the first case, for example, ERTS-A tapes are anticipated for analysis at our facility, employing various automatic and semi-automatic techniques. The pattern recognition routines from LARS (Purdue) are adapted to our CDC 6600 computer facility through which a terminal link is established for greater interactive uses. Also, we are concentrating heavily on practical studies of the texture analysis technique as an improvement over

conventional manual means of deriving subjective information from photographs. Initial tests of our color display components reveal them to be very useful in the image processing area--especially where it is desirable to present results, in their most interpretable format, to the investigator. Examples of each of these activities are discussed next.

A. Spectral frequency data classification experiments.

Two types of terrain have been studied and subjected to our version of a pattern recognition program: rangelands and agriculture. In both cases, our input data to be classified were derived from optical density values scanned with the FRSL scanning microdensitometer. In the case of agricultural fields, we have directed our attention to the Arizona area where extensive ground truth information exists. We have digitized high altitude, black-and-white photos obtained from the NASA aircraft in May 1970. Three bands were used: Pan-58, Pan-25, and Infrared-89B to comprise a three-channel classification scheme. The area selected for training and testing is the "16-square mile" test area which we continue to monitor at the time of each successive overflight. Eight categories were chosen for recognition:

- |              |                |
|--------------|----------------|
| 1. Alfalfa-1 | 5. Wheat       |
| 2. Alfalfa-2 | 6. Alfalfa-cut |
| 3. Barley    | 7. Bare Soil   |
| 4. Cotton    | 8. Sugar Beets |

The classification summary in Table 4.2 lists the preliminary results achieved to date. Much more work must be done with these routines to



determine optimum dates, scanning parameters, and ground truth deficiencies (as exhibited by the difference in categories 1 and 2, which appeared to require separate labels for recognition). No illustrations of the automated categorization are presented in this report because of the difficulty of acquiring legible computer print-outs of this size for photo reproduction.

In our rangelands investigations, we employed color infrared photography which had been acquired at extremely low altitude and used a "color separation" procedure to extract three channels of data corresponding to the emulsion layers of this film. Five features were selected for automatic recognition in the data: two different kinds of test panels, two brush species, and the background complex of bare soil and mixed grasses. Figure 4.16 contains an illustration of this imagery. Summary statistics for the classification are presented in Table 4.3.

#### B. Spatial frequency classification experiments.

Our texture analysis studies have concentrated upon the forest environment as a test case. The objective is to develop a procedure for taking aerial photos which have been manually "typed" as to homogeneous units (forest stands) and to digitally scan these types to derive statistics which can be used in the classification routine. Textural signatures are analogous to tone signatures in this respect. To date, we have worked towards the prediction of several forest stand parameters of interest to the forest land manager. Table 4.4 shows preliminary results of our ability to predict from photo-scanned statistics that which we have previously measured as ground truth.

TABLE 4.2 AUTOMATIC CLASSIFICATION OF CROP TYPES FROM SPECTRAL  
DATA IN THE 16-SQUARE MILE AGRICULTURAL TEST AREA OF  
MARICOPA COUNTY, ARIZONA

CLASSIFICATION SUMMARY BY TRAINING FIELDS

CLASS	NO OF SAMPS	PCT. CORCT	NO OF SAMPLES CLASSIFIED INTO							
			ONE	TWO	THREE	FOUR	FIVE	SIX	SEVEN	EIGHT
Alf-1	35	82.9	29	6	0	0	0	0	0	0
Alf-2	156	46.2	80	72	0	0	0	1	2	1
Barl	168	100.0	0	0	168	0	0	0	0	0
Cot	77	100.0	0	0	0	77	0	0	0	0
Wht	171	81.3	0	0	0	2	139	0	28	2
Alf-cut	36	97.2	0	0	0	1	0	35	0	0
Bare	96	80.2	0	0	0	1	18	0	77	0
SB	121	98.3	0	0	0	0	1	1	0	119
TOTAL	860		109	78	168	81	158	37	107	122

OVERALL PERFORMANCE = 83.3

TABLE 4.3 AUTOMATIC CLASSIFICATION OF RANGELAND TYPES FROM SPECTRAL  
DATA PROVIDED BY LOW ALTITUDE INFRARED EKTACHROME PHOTOGRAPHY  
OF THE NASA HARVEY VALLEY TEST SITE

CLASSIFICATION SUMMARY BY TRAINING FIELDS

CLASS	NO. OF SAMPLES	% CORRECT	NUMBER OF SAMPLES CLASSIFIED INTO				
			BRUSH 1	BRUSH 2	BACK	PANEL 1	PANEL 2
Brush 1	42	81.0	34	5	3	-	-
Brush 2	45	73.4	4	33	8	-	-
Background	66	95.5	2	1	63	-	-
Panel 1	49	97.9	-	-	1	48	-
Panel 2	42	100.0	-	-	-	-	42
TOTAL	244		40	39	75	48	42

OVERALL PERFORMANCE: 87.6%



Figure 4.16. Photo illustration of the rangeland area which was studied for automatic classification of the categories annotated above. Results of the study are discussed in the text. No photo illustrations of the computer-generated classification results are included in this report because of the problem of obtaining good quality inputs for photographing. However, we are currently completing routines which will enable display of such results on our CRT devices.

This page is reproduced at the back of the report by a different reproduction method to provide better detail.

TABLE 4.4 SUMMARY OF REGRESSION ANALYSIS ON FOREST SPATIAL FREQUENCY DATA

	MULTIPLE $r^2$	STANDARD ERROR OF EST.	MEAN	STANDARD DEVIATION	UNITS
Volume*	0.97	1921.0	13594.0	4339.0	Bd ft/Ac
Basal Area*	0.95	13.0	91.4	23.9	Ft <sup>2</sup> /Ac
No. of Trees*	0.96	9.2	44.9	18.1	Trees/Ac
Avg. Stand Height*	0.93	9.6	76.9	13.3	Feet
% Crown Closure <sup>+</sup>	0.96	3.5	17.6	6.0	%
Avg. Crown Diam. <sup>+</sup>	0.98	2.2	20.8	5.6	Feet

\* = on-site measurements

+ = photo estimated by conventional manual methods

Figures 4.17 and 4.18 show the results of generating predictions from 24 scans of photography obtained over the NASA Forestry Test Site. The areas were selected to fall within the boundaries of stratified vegetation types determined conventionally by photo interpretation methods. Scanning was performed on a single photo, oriented normal to the shadows to minimize textural changes due to illumination angle and photo scale. A multiple linear regression equation was generated for each of the variables measured by the ground data acquisition crews and photo interpreters. (See Table 4.4.)

### C. Color Displays

More and more of our attention is being directed toward the color display aspects of automatic feature recognition applications. The illustrations contained in this progress report are contained as

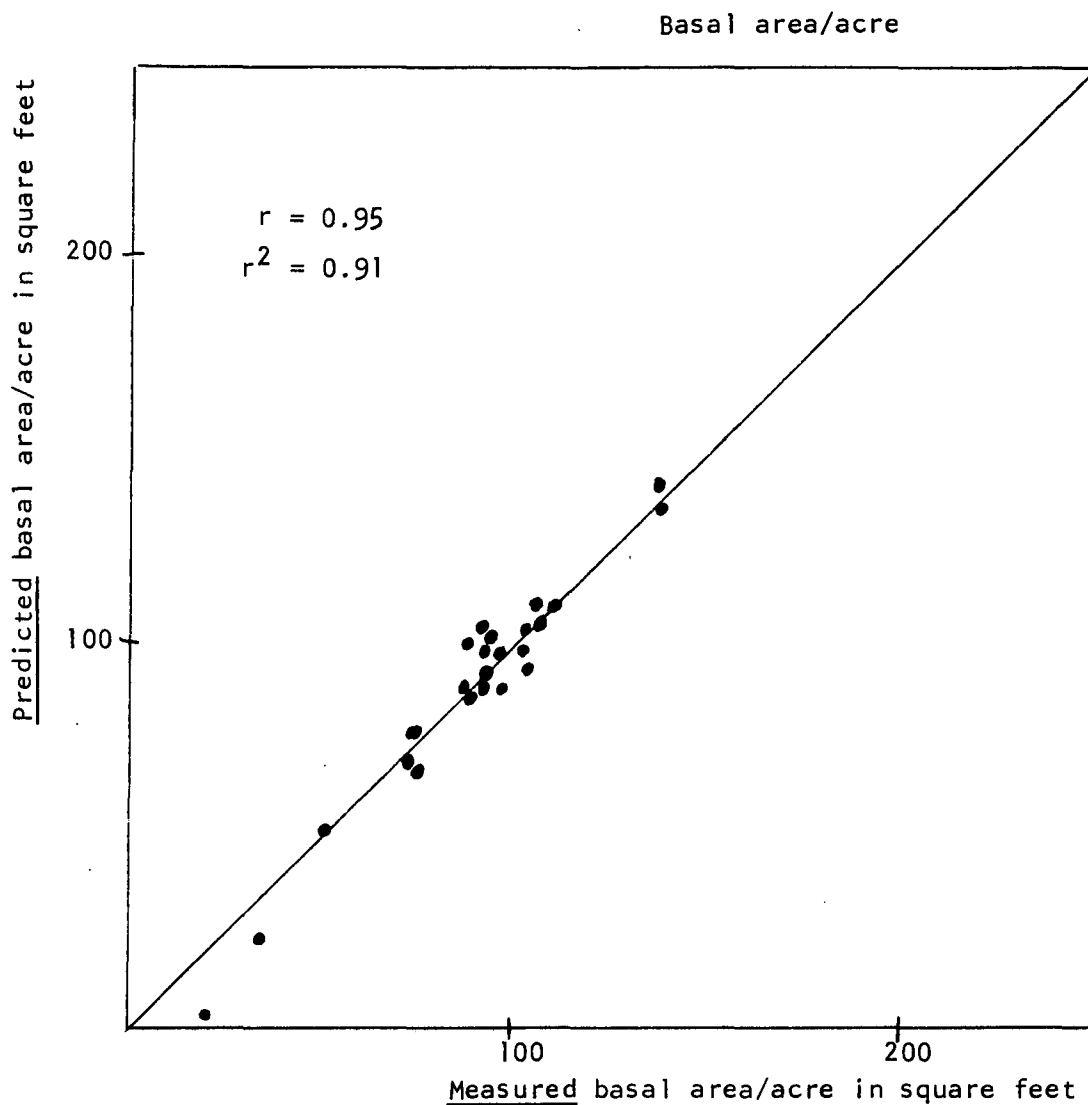


Figure 4.17. This plot shows, for representative timber stands, the relationship between measured basal area per acre (derived from ground truth records) and that which is predicted using textural energy coefficients of the same ground sites as imaged on aerial photos and optically scanned for spatial frequency data. The technique is described in the text.

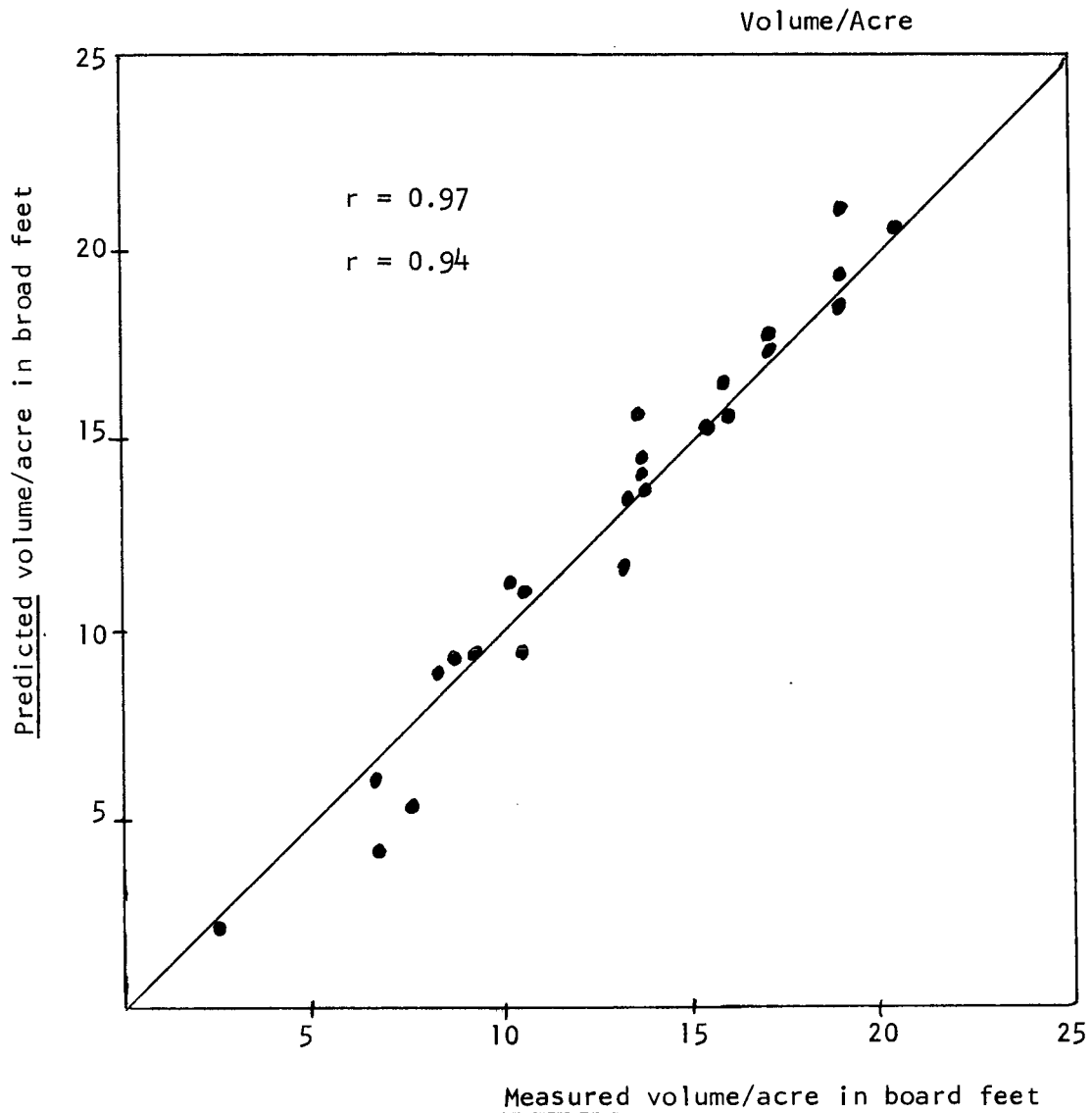


Figure 4.18. The ability to "predict" volume/acre for various timber stands by using textural energy coefficients is shown by the above relationship. Description of the procedure is presented in the text. A large number of relationships are being studied using this technique of relating information derived from actual ground measurements to that which is derived from scanned images of these ground measurement sites.

examples of the type of results which one can achieve using this format of presentation. The existing subsystem for color display is single-channel. This greatly restricts the discriminatory potential which the technique conceptually possesses. We have continued to describe our original three-channel color subsystem as an area of worthy activity under the "Future Proposed Research" section of this progress report.

The examples chosen for demonstrating the color display are varied in application to give some idea of the variety of possible applications which can be investigated. Figures 4.19 to 4.22 show these various examples.

#### Data Bank Storage and Retrieval Capabilities for Resource Management Applications.

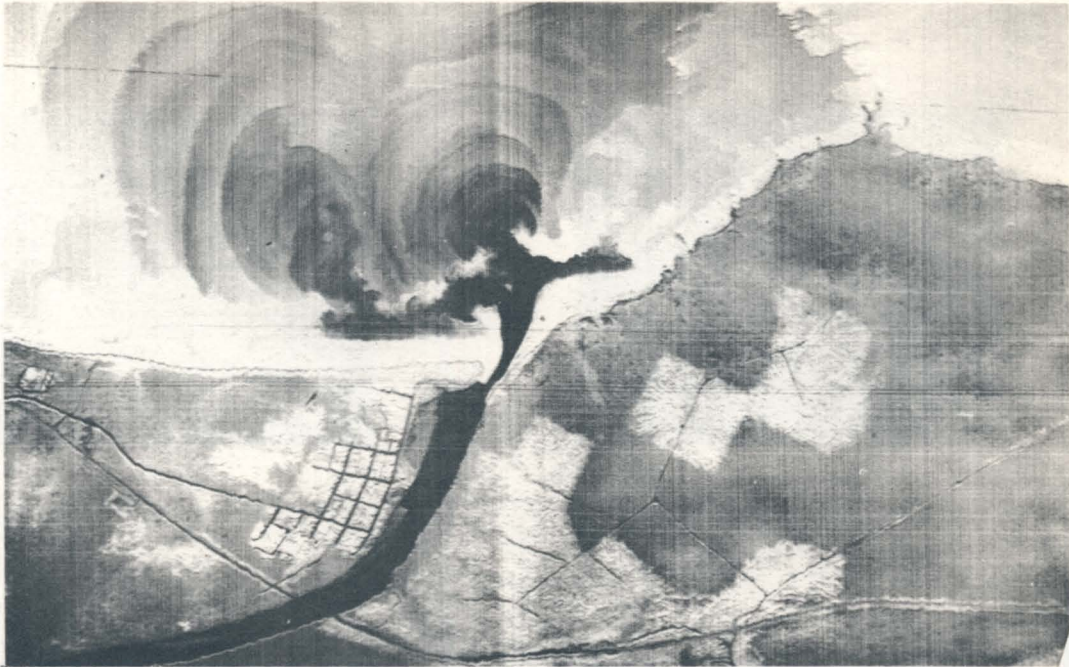
Contained in the following pages are several figures indicating the possible application of the MAPIT routines in a "management oriented" situation. These illustrations (Figures 4.23 to 4.31) depict the output maps for a minimal set of resource profiles. The hypothetical problem used to demonstrate MAPIT was, using some of the profiles contained in a portion of the Bucks Lake Forestry Test Site, to select those areas deemed suitable for conversion of land use from brush species to commercially renewable pine forest stands. The constraints of the problem are:

- . the maximum elevation of land which is to be converted must be less than or equal to 5000 feet
- . the slope of the land must be no greater than 35% in



16  
Figure 4.19. CRT color display for Hydrologic investigations. Shown on the preceding page are four varying color display presentations derived from the density data contained in the larger black-and-white photo example. This larger example is in fact photo data extracted from an airborne thermal infrared scanner device of a small stream emptying into the Pacific Ocean along the coast north of California. The airborne infrared scanner can be an important source of information regarding the thermal regimes of an area. It has a day-or-night sensing capability (this example was recorded at night) and the image densities (tones) are directly correlated with the emitted thermal properties of features in the scene. Since this example is the "negative" of what usually is presented to the image analyst, dark tones represent "warm" features and light tones represent "cold" features, thermally. The warmer stream is seen to empty and mix with the colder Pacific Ocean waters. The large square areas on the grey background consist of Douglas Fir stands which are "clear-cut."

The four color display examples illustrate the flexibility for presenting the data for subsequent interpretation. Different degrees of color mixing are shown using the Terminal/Display components as they presently operate. In the upper left color example, only a small portion of the grey tones are "enhanced" in blue and green; in the upper right, the warm stream flow is made to appear orange in contrast with the surrounding tones; in the lower left example, the "green" CRT phosphor is suppressed and the display is presented in color values of reds and blues; in the lower right example, the grey tones are all assigned a range of colors for enhanced display, ranging from the coldest features (in light green) through red, orange, violet and blue, to black, the latter representing the warmest features.



NOT REPRODUCIBLE



Figure 4.19. See caption on facing page.

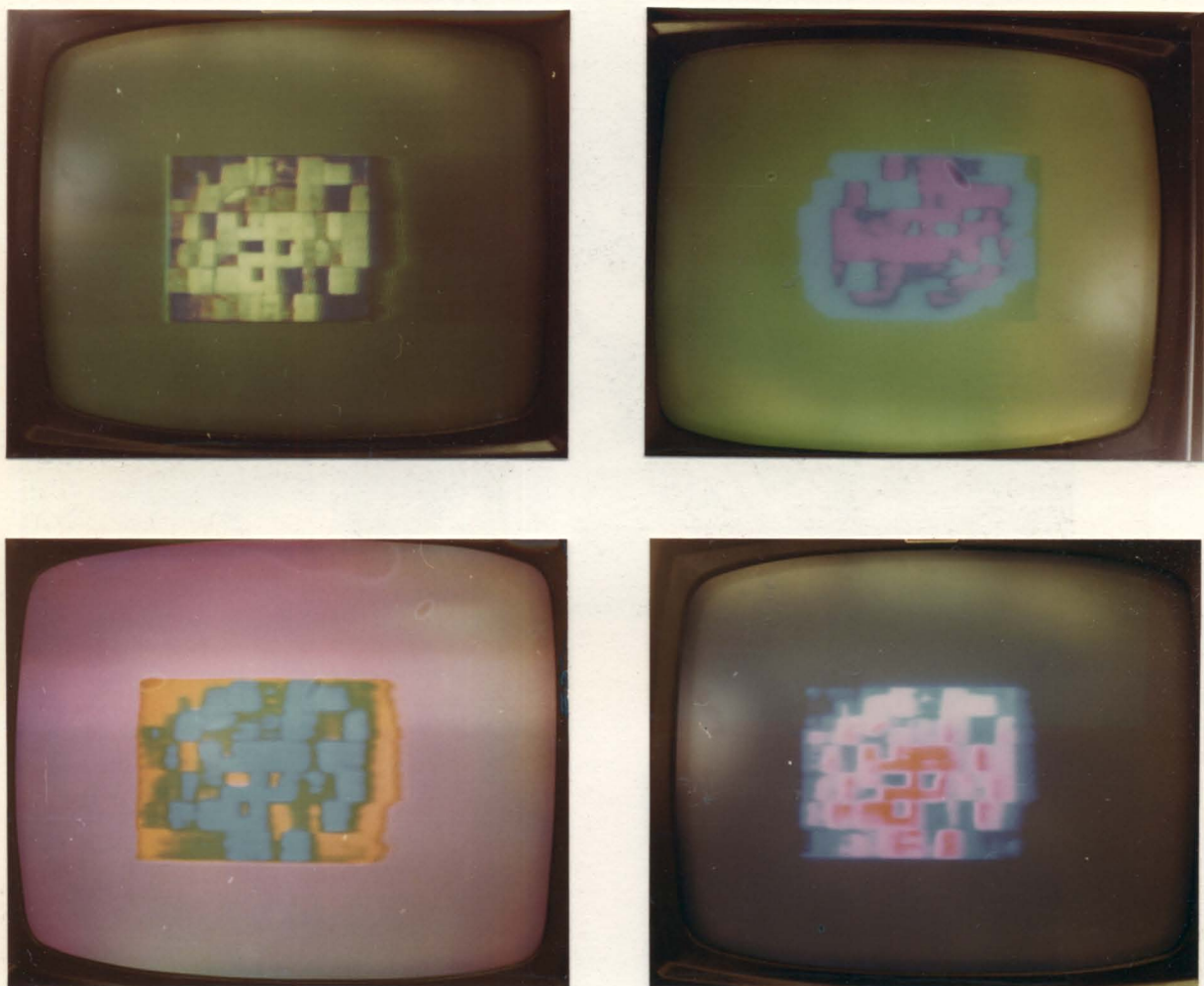


Figure 4.20. Color CRT displays for Agricultural Surveys. Four varying color displays are shown above to illustrate the flexibility in performing crop classifications and subsequently presenting results in a color mode for evaluation. In the above examples, high altitude photo data are shown under different color mixing formats. Studies are planned which will document that combination of colors which is most useful to the image analyst who is making the tone classifications.

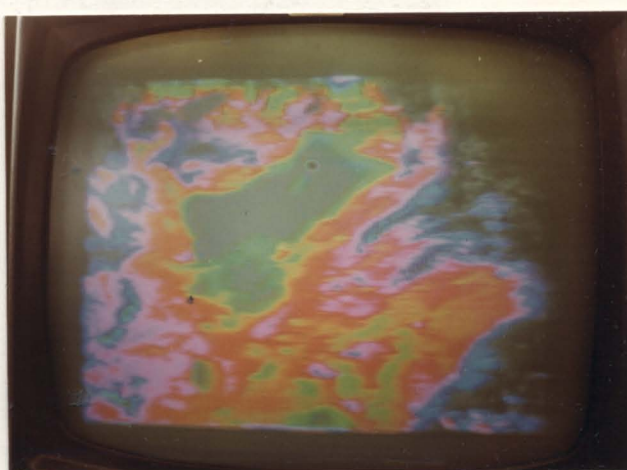
NOT REPRODUCIBLE





NOT REPRODUCIBLE

Figure 4.21. Color displays for snow and cloud delineations. The density slice and color display technique is readily accomplished with snow and clouds as features of interest, as the above illustrations reveal. The input data were obtained from black-and-white aerial photos of a portion of the NASA Bucks Lake Forestry Test Site in Northern California. Snow delineations are being investigated as a means of quantifying their relationship to stream flow performance. In the left example above, both clouds (orange) and snow (white) are "enhanced" from the background tones. In the right example, the background tones have been assigned colors according to grey tones, but the cloud and snow features are not so readily discernible.



NOT REPRODUCIBLE

Figure 4.22. Color displays for wildland vegetation investigations. Shown above are four varying degrees of feature classification and enhancement for complex wildland vegetation resources in the Bucks Lake Forestry Test Site. In the top left Silver Lake is coded light blue and the native hardwood vegetation in this area is coded light green. Other features are not color coded. In the top right is another presentation with more colors being assigned to different tones in the scene. The two examples at the bottom show the complexity of color presentation which is possible with this technique. They also illustrate the need for close coordination between man and machine in order that the image analyst is not "overwhelmed" by the data being presented.

- . order for bulldozers to operate effectively in the conversion
- . all aspects of NORTHWEST, NORTH, or NORTHEAST must be rejected as unfavorable pine growing sites
- . acceptable soils for the conversion to plantations are COHASSET, AIKEN, or CORNUTT; reject all others as undesirable
- . the CORNUTT soil must be on less than or equal to 20% slopes in order to minimize its risk of erosion, and
- . the vegetation, of course, must be presently a brush species.

The illustrations sequentially show the "raw" data maps from which the resource information is built up: (1) an elevation map of the area with 200 foot contour intervals shown, (2) a percent slope map of the area with 5% intervals, (3) an aspect map with 45 degree intervals, (4) a soil base map of the area under investigation, (5) a general vegetation base map of the area, and (6) a "profile" map generated from the raw data maps showing the acceptable portion of the area under constraint number 1 above.

The additional illustrations show the management information desired, namely (7) the areas which satisfy all of the six original constraints, and (8) an additional map which has been stratified into GOOD, MEDIUM, and POOR relative investment opportunities, based on the soil type information. The parameters most affecting the relative investment opportunity of a site are the soil type and the slope of the land. Since COHASSET soil is a more productive soil than either AIKEN or CORNUTT, it should receive a higher priority for conversion than the others. Hence the final map shows, of the total "acceptable"



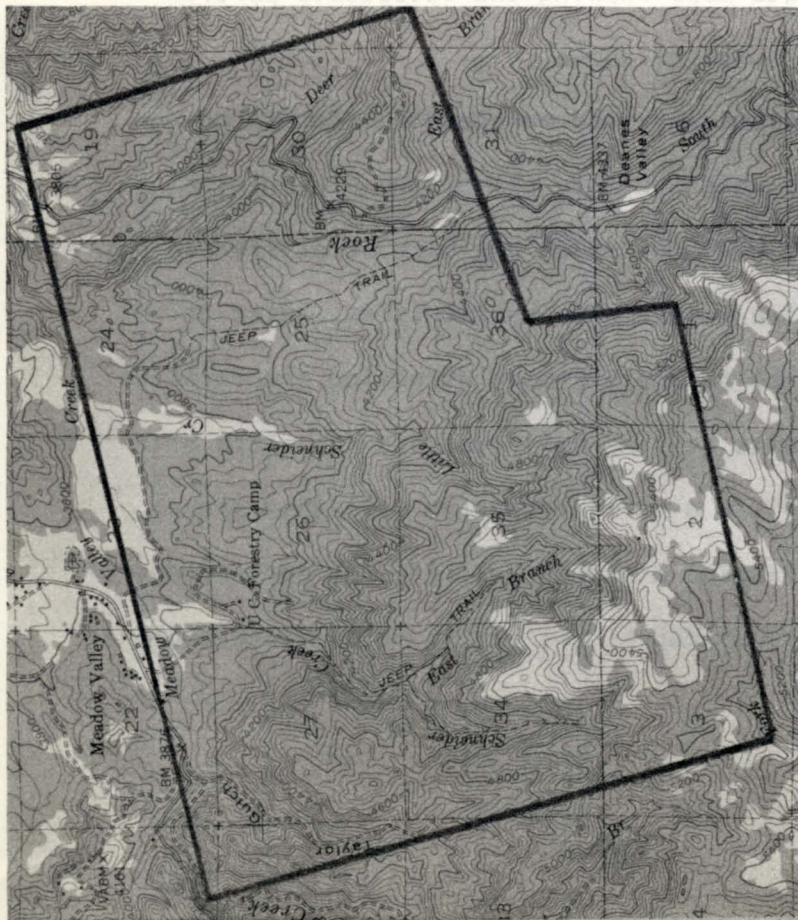
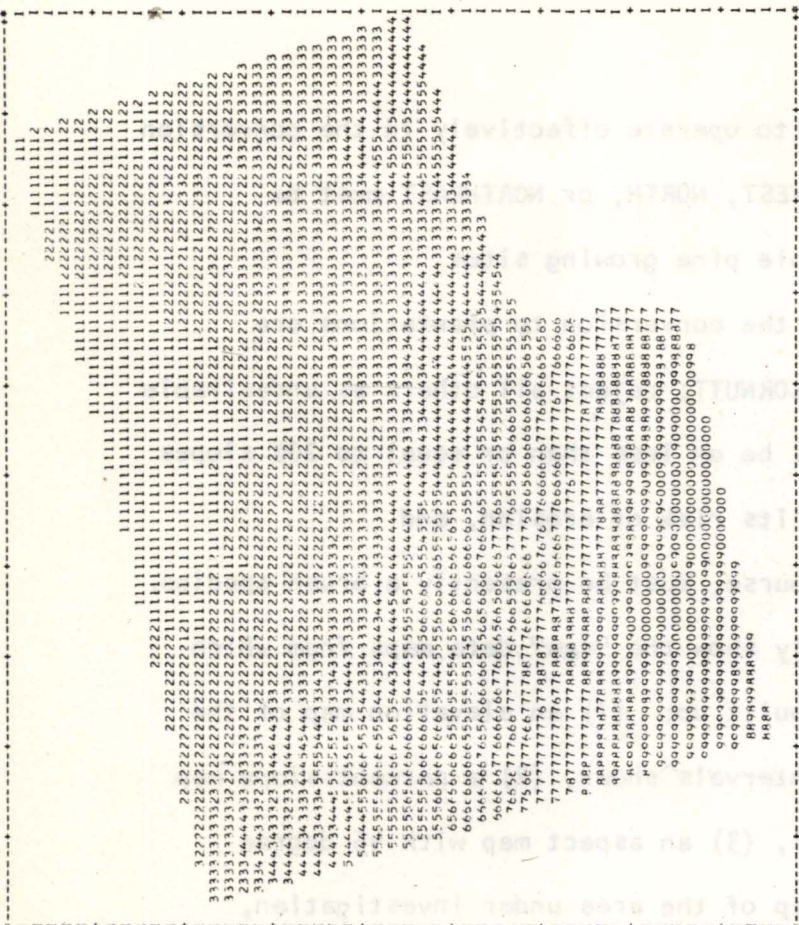


Figure 4.23. The illustration on the left shows a portion of the NASA Bucks Lake Forestry Test Site in Northern California with the boundary designating the region from which source inputs were encoded for storage and retrieval purposes using MAPIT. The computer printout on the right shows 10 slices of information about elevation for the area of study. Each cell represents approximately one hectare of ground-equivalent area. The slices represent 200' contour intervals for display purposes. The stored data contain elevational resolution that is sufficiently good to permit the drawing of contours at a 40-foot interval. Such a map, or profile, is considered to be a "raw base map" from which other information can be generated, as indicated by the remaining examples in this series.



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Figure 4.24. The raw base map on the left represents per cent slopes at five percent intervals (slices). The map on the right is another raw base map containing data on aspect, with resolution equal to  $45^{\circ}$ .



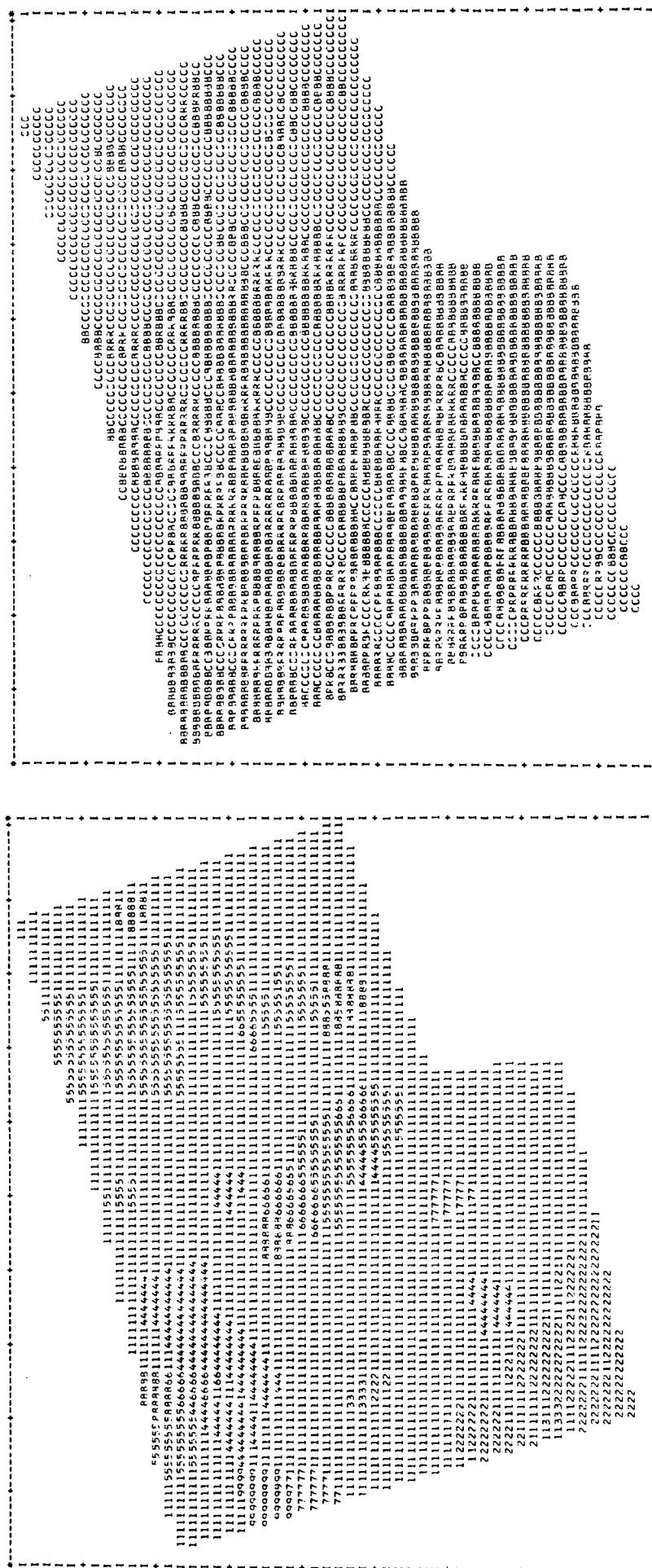
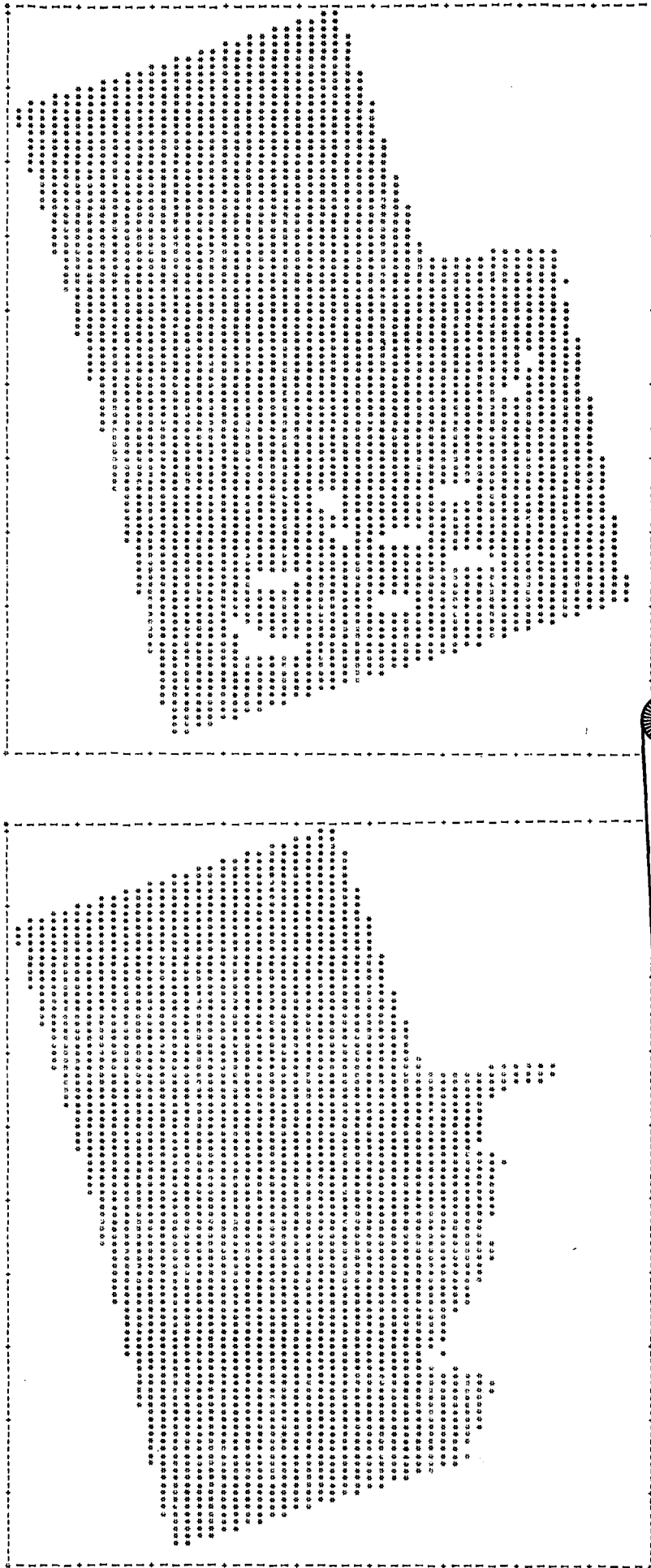


Figure 4.25. The raw base map on the left is encoded to represent nine soil types which exist in the area of study. The map on the right represents the raw base data for the broad vegetation types found in the area. "C" denotes commercial conifer, "B" denotes brush species, and "R" represents riparian vegetation types.



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Figure 4.26. The printout on the left shows all cells which are less than or equal to 5000' altitude, as per the text problem constraint. The display on the right represents all cells which satisfy the requirement that favorable slopes are those which are less than or equal to 35 per cent.

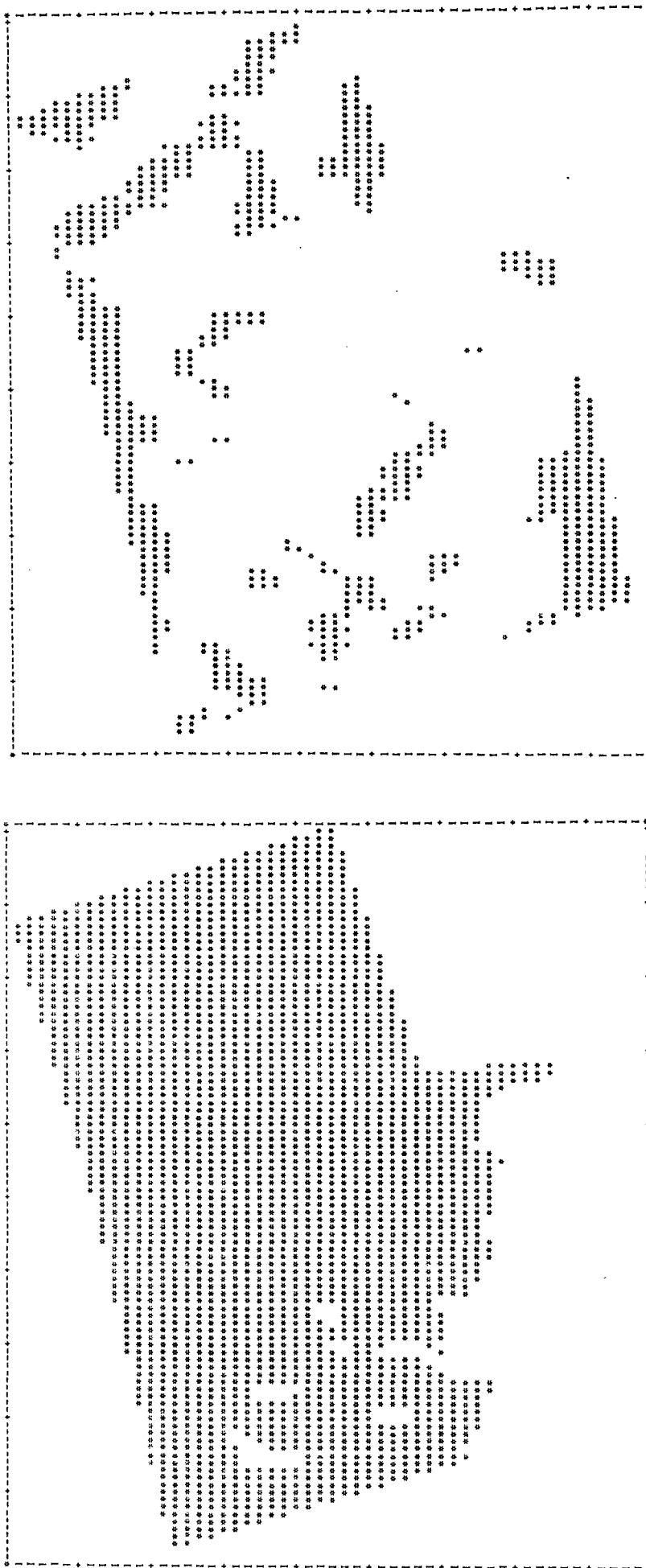
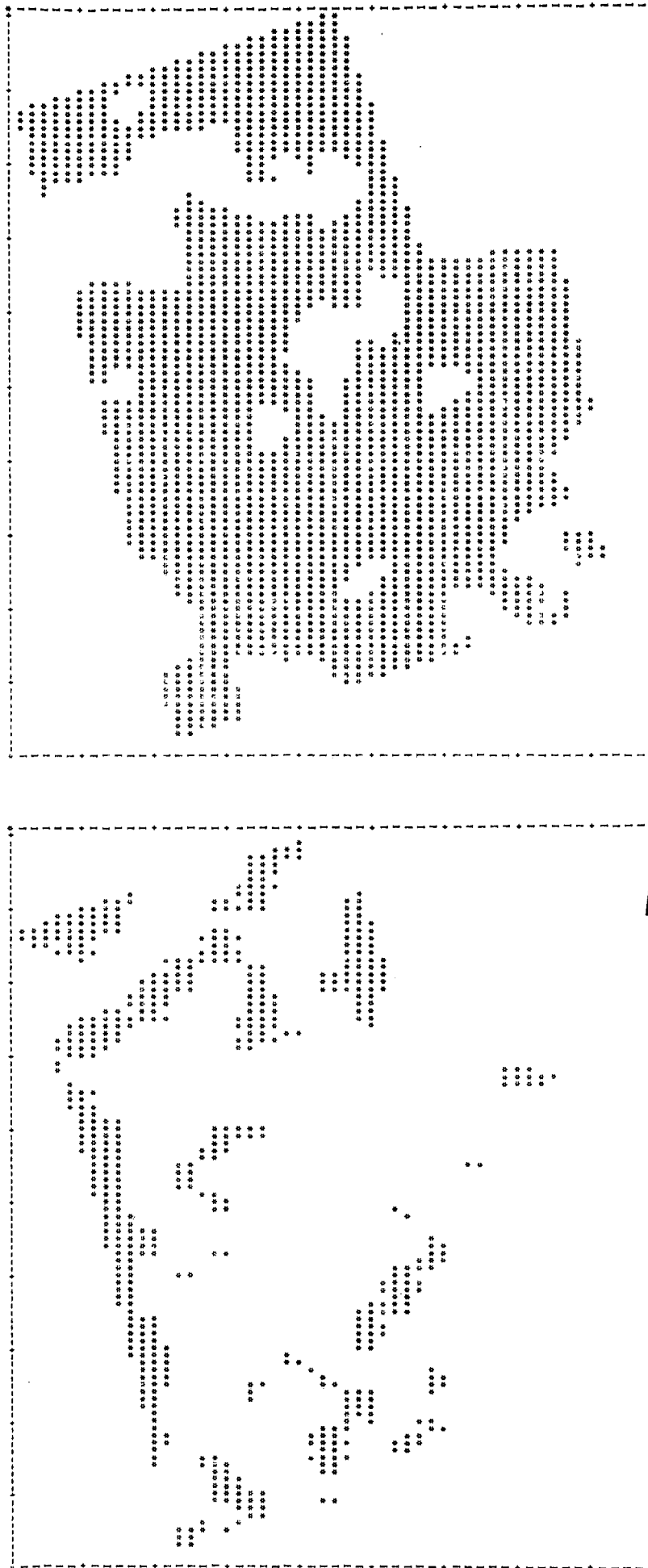


Figure 4.27. The display on the left represents all cells which satisfy the problem constraints of both elevation and slope, namely, a combination of favorable cells in both maps appearing in the previous figure. The display on the right represents those cells not residing on a NW, N, or NE aspect, since these are deemed as unfavorable conversion sites under the constraints of our problem.



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Figure 4.28. This display on the left shows those cells which comply with the problem constraints of (a) elevations less than or equal to 5000', (b) slope must be less than or equal to 35 percent, and (c) aspect must not be NW, N, or NE. The display on the right represents those cells with a soil type of either COHASSET, AIKEN, or CORNUTT, all deemed most favorable among those which exist in the study area.



Figure 4.29. The display on the left represents the information contained in the left portion of the preceding figure, with the additional constraint of soil type represented by the right portion of the preceding figure. In other words, the two profiles of the previous figure are combined in the above left display. The display on the right, above, is an additional restriction that CORNUTT soil must be on a slope which is less than or equal to 20 percent, to minimize erosion potential from a conversion operation.

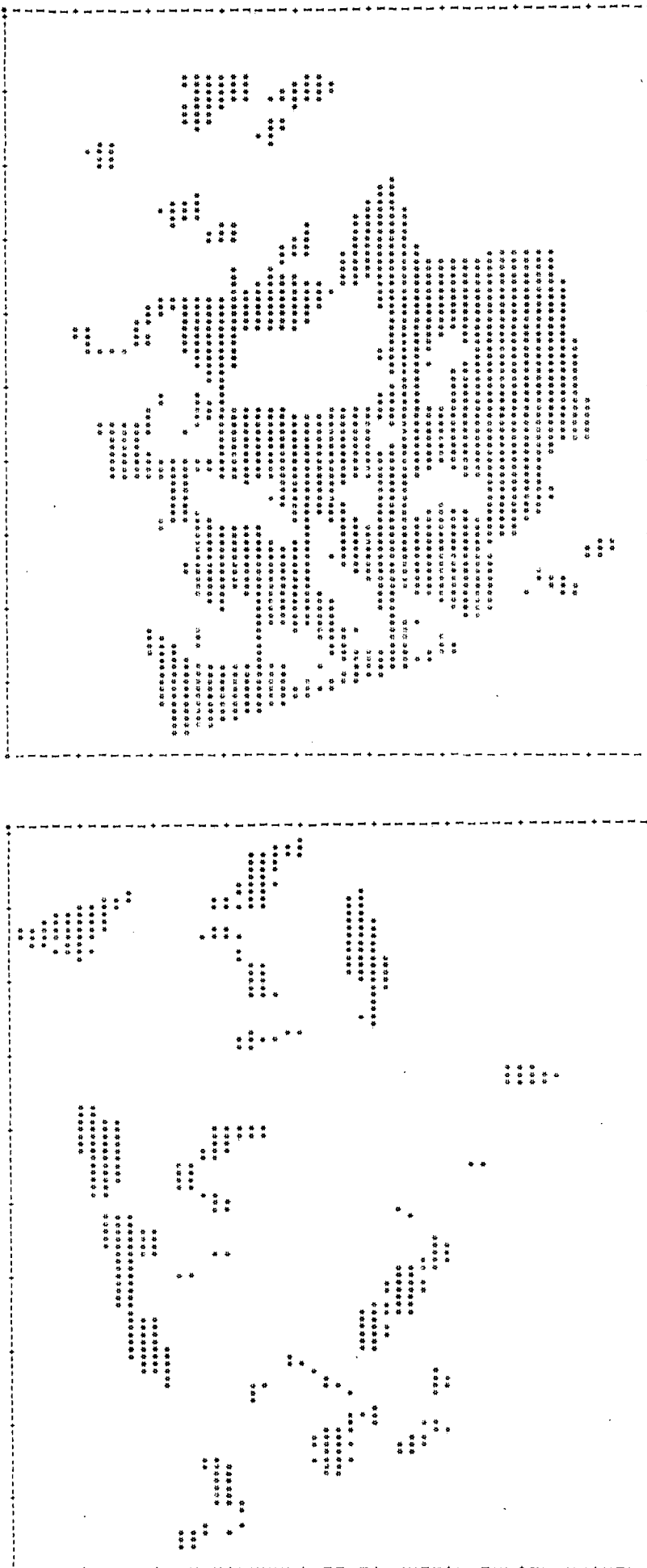


Figure 4.30. The left display represents the combined maps from the previous figure. The display on the right shows only the cells vegetated by BRUSH since these are the areas we wish to consider converting to forest plantations under the problem constraint.

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cells within the area under examination, a priority ranking of them for conversion purposes.

#### 4.4.2. Proposed Future Research Activities

It is fairly clear as to the direction which our unit's research activities should take in the immediate future, based on our efforts this past year. The only "new" aspect of our plans calls for the integration of our program with data which are to be derived from the ERTS-A satellite and from supporting high-altitude aircraft. But this is a logical transition, since this is the direction we have been anticipating in our first year of study. Specifically, we propose to conduct research designed to develop applications of remote sensing for the inventory of vegetation resources in each of the following areas:

A. Continue work with the modified pattern recognition programs we now have, and for which we are completing an interactive data link with a computer facility, to optimize their use. This effort has a two-fold objective: to examine the point-cell classification efficiency in a variety of terrain land-use applications; and to develop some experience in the mechanics of determining the best mix of man with machine for such resource surveys.

B. Continue work with the scanning of spatial frequency data for the purpose of using "textural signatures" in a classification scheme as well as spectral signatures. An effort will be made to combine both spectral and spatial analyses in the same "multichannel" program.



C. Develop routines to handle ERTS-A tapes (9-track digitally recorded) as partial input to a system of display and sampling for a multi-stage approach to resource survey application. It is anticipated, for instance, that manual feature typing may be done at the satellite altitude stage with supplementary scanning done at subordinate levels in a sampling scheme to determine important resource information for the land manager. This approach will be attempted first with the forest resource to determine its efficiency over conventional manual methods, using the textural signature approach described earlier.

D. Upgrade our single channel input color display system to enable three channels of input. It is estimated that \$10k would be necessary for the additional equipment purchases and the in-house interfacing operations required to complete this subsystem. The basic components of the system as originally proposed by us consist of:

- 1 color TV monitor
- 3 scan conversion memory units (Hughes Model 639)
- 3 small B/W monitors
- 1 synchronization unit (for congruency)

In addition, some electronics equipment will be needed to interface with the existing system. We currently have the components necessary for a single channel color display system. The multi-image capability will greatly enhance our ability to analyze multiband and multirate images in a multi-dimensional framework, rather than through single inputs. Our many years of research experience have

indicated that many features--especially vegetation features--require multidimensional information in order to automatically recognize them.

E. Based upon the successes of scanning artificial stream channels with dispersive dyes injected into them, we propose to extend the technique to actual coastal waters for the purpose of locating effluent discharges and determining the rates of spread of these effluents. We propose to investigate the procedure with sensor data obtained at higher and higher altitudes to determine the limits for detecting effluents and measuring their dispersive characteristics.

#### 4.5. REPORT OF THE SPECTRAL CHARACTERISTICS UNIT

In keeping with the philosophy of the Laboratory that the most meaningful measurements of spectral reflectivity for remote sensing purposes are those that are made in the field, the Spectral Characteristics Unit continued in the development of the capability to obtain field data. Equipment development has been predicated upon the need for a low-cost research tool, versatile, amenable to modification, and useful for determining the spectral characteristics of natural surfaces and features which must be examined in their natural undisturbed environment, and which may be remotely located and difficult of access. To date, most of the equipment for data acquisition has utilized off-the-shelf components which have been modified and interfaced to form a versatile data gathering system which can be used

to measure irradiance as a function of wavelength for the energy that is incident upon, and reflected from, natural features.

#### 4.5.1. Work Performed During the Period Covered by This Report

Field measurements of reflected radiation in the 375-1200 nanometer wavelength range were made for several brush species within the Feather River watershed during this past season. An analysis of the data from a brushfield representative of thousands of acres of the upper elevation watershed is presented. Four species of brush are included: manzanita, (Arctostaphylos patula); huckleberry oak, (Quercus vaccinifolia); tobaccobrush, (Ceanothus velutinus); and chinquapin, (Castanopsis sempervirens). The data collection and analysis methods are discussed and the types of hardware and software used in the project are detailed in the sections which follow.

##### Hardware for Reflected Spectral Irradiance Measurements.

###### A. Spectroradiometers

Two spectroradiometers were used to cover the spectral range 350-1200 nanometers and acquire data about spectral radiation reflected from the features of interest. They are identical except for the detectors and monochromator gratings which must be different in order to cover the required wavelength ranges. One spectroradiometer is effective in the spectral range 350-800 nm; the other in the range 700-1200 nm. The spectroradiometers are modular units consisting of (1) beam input optics, (2) a monochromator housing, (3) a detector unit and (4) an indicator unit. The first three units physically mount together into one optical unit by means of twist-lock bayonet

attachments. The indicator unit is connected by an electrical cable.

The beam input optics along with a cone and filter holder restrict the field of view to  $14^{\circ}$ , diffuse the light and direct it to the entrance slits of the monochromator housing. Changeable optical filters reject the short wavelength harmonics which would be generated by the grating monochromator.

The monochromator housing utilizes a plane diffraction grating to angularly disperse the light according to wavelength. The grating can be rotated and in conjunction with the necessary mirrors and lenses directs the selected wavelength bundle to the exit slit. The bandwidth about the central wavelength is from 5 to 20 nm in the visible range and from 10 to 40 nm in the near infrared range, depending on the width of the entrance and exit slits.

Light leaving the exit slit falls onto a photodiode in the detector head. The strength of the electric current through the photodiode circuit is proportional to the light incident on the detector.

The indicator unit provides a bias voltage across the photodiode and measures the current flow. Operation can be from external line voltage or from a self-contained battery power supply. The unit houses the necessary electronics for operating in various modes, selecting sensitivity ranges and other control functions. The indicator unit also has a 0-10 mv signal output available for connection to an external recorder.

## B. Data Recording

The data recording unit houses a digital voltmeter, incremental digital tape recorder/reproducer, control switches, and necessary electronics and power supply for interfacing the units and formatting the data. The external recording output of the indicator unit is connected to the digital voltmeter which provides a visual display of the output and also functions as an A/D converter with BCD output. The binary data output of this device is recorded on the tape unit by depressing a data entry thumbswitch. At the same time, a number indicating the position of the spectroradiometer sensitivity range switch is recorded. At the beginning of each set of data a number selected from eight thumbwheel switches and representing the data set identification number, the number of data entries, and the wavelength interval is entered on the tape by means of a code entry switch. This number identifies the data set for all subsequent operations.

## C. Power Supply

Power for the operation of the equipment in the field is provided from an automotive type 12 volt battery. The digital voltmeter and the incremental tape recorder require a nominal 115 volt, 60 Hz power supply. Both units are non-critical about the voltage and frequency requirements and are adequately supplied by the output from an inexpensive current inverter powered by the 12 volt battery.

## Hardware for Incident Spectral Irradiance Measurements

### A. Spectroradiometer

The spectroradiometer used to measure incident light operates through the spectral range 380-1300 nm. Sunlight and skylight are

incident upon a horizontal cosine response diffuser screen. Light from the diffuser screen passes through a mechanical chopper, an optical entrance slit, and then a wedge interference filter monochromator. The wedge interference filter can be moved past the entrance slit by a drive motor thereby producing a continuous spectral scan. The monochromator transmits a bandwidth of 15nm in the visible part of the spectrum and 30nm in the near infrared part of the spectrum which is incident upon a photodiode detector. The signal output is read on the unit's indicating meter or is taken from the external signal output. Approximately a 0-10 mv signal is available. The center wavelength being sensed at any time can be read from the monochromator dial for direct readings or as a function of time measured from an electrical timing spike if recording the signal externally.

#### B. Data Recording

In the FRSL system, the analog output of the spectroradiometer is input to an FM recording adapter which converts it to a frequency output. The frequency output varies through a range of 500-3000 Hz and is recorded on an audio tape recorder with a servo controlled capstan motor.

When the signals are to be retrieved they are input to a frequency discriminator which converts frequency to voltage. This analog voltage signal is input to the computer through an analog to digital converter.

### C. Power Supply

Power for the operation of all the field equipment is derived from a 12 volt battery. Several days of operation can be sustained on each charge. All the components operate directly from the 12 volt supply except the FM recording adapter which derives 115 volts from a small inverter in the mechanism controlling the automatic operation of the spectroradiometer.

### Software.

Programs currently exist which will read the digital field data tapes of reflected energy; they also will correct for detector sensitivity at each wavelength and will output the data in absolute radiometric units, i.e., Watts/cm<sup>2</sup>/nm, in tabular form on a CRT or teletype or rewrite the data on an addressable tape for future access. Each addressable tape contains a directory which lists the tape address of each set of data identified by its sequential code number.

Routines have also been written to take the analog data from the radiometer measuring incident light and reformat it, correct for detector spectral sensitivity, and output the data in tabular form.

These programs as written have considerable flexibility and parts of them will be used for other data handling functions as well.

### Data Collection.

Measurements of the spectral radiation reflected from the brush plants were made in the field under natural illumination using the equipment previously described. The spectroradiometers were set

up on a tripod such that the instruments were approximately four feet above the top of the brush. All measurements were made at an azimuth of  $90^{\circ}$  to the sun and with the spectroradiometers at about  $15^{\circ}$  from the vertical. Three sets of measurements were made over each of the plant species. The data from these measurements are shown in Table 4.5.

At fifteen minute intervals measurements were made of the spectral irradiance incident upon the area in order to be able to standardize all the reflectance measurements to a single illumination condition.

The standardization of reflected energy is accomplished by obtaining, for each wavelength, a ratio of the irradiance incident at the time for which the data are being standardized to the irradiance incident at the time of the measurement of reflected energy. The measured energy reflected at each wavelength is multiplied by the ratio for that time and wavelength to obtain a standardized measurement. A graph of the standardized data is shown in Figure 4.33 where the means of reflected energy from three data sets for each species are plotted against wavelength.

#### Data Analysis.

The data were analyzed using Duncan's multiple range test to determine if statistically significant differences exist among the ranked means of irradiance as reflected from the four brush species at each of twenty-four wavelengths. Summary sheets (Table 4.6) show the results of this analysis. The data are shown in terms of



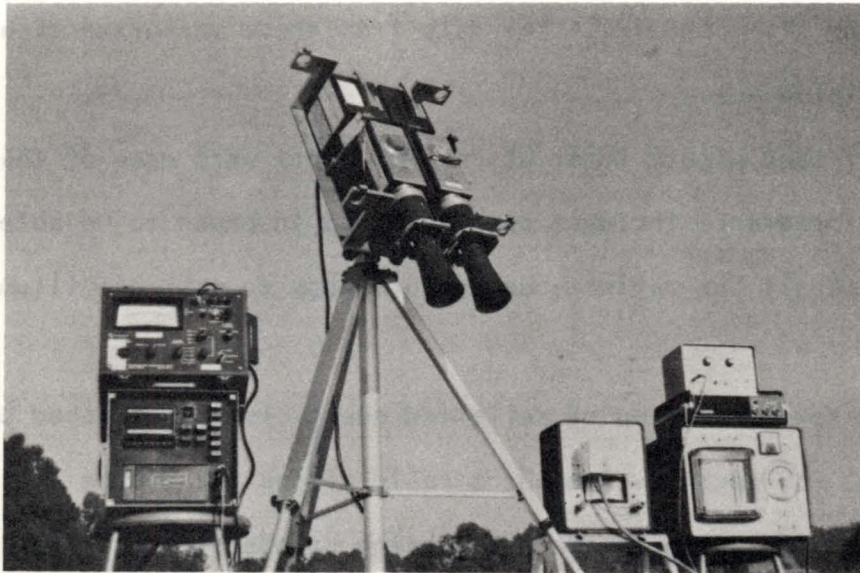


Figure 4.32. Instruments used to make field measurements of reflected and incident energy in the 350-1200 nanometer wavelength range.

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TABLE 4.5 IRRADIANCE MEASUREMENTS OF REFLECTED ENERGY 7/29/71

01500000 Chinquapin

time: 1203

WM	WATTS/CM <sup>2</sup> /NM	WM	WATTS/CM <sup>2</sup> /NM
0375	+.3496801E-07	0700	+.4507691E-06
0400	+.6625769E-07	0750	+.1141626E-05
0425	+.9255472E-07	0800	+.1164285E-05
0450	+.1323353E-06	0850	+.1402215E-05
0475	+.1517893E-06	0900	+.8919304E-06
0500	+.1887271E-06	0950	+.2869976E-06
0525	+.3732738E-06	1000	+.5917310E-06
0550	+.733223E-06	1050	+.5722165E-06
0550	+.4332121E-06	1100	+.4378349E-06
0575	+.3575410E-06	1150	+.2322221E-06
0600	+.3190256E-06	1200	+.3493727E-06
0605	+.2219818E-06		
0650	+.2359207E-06		
0675	+.2152293E-06		
0700	+.5521303E-06		
0720	+.5732541E-06		
0725	+.1376236E-05		
0750	+.1022401E-05		
	+.7227103E-07		

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01500000 Chinquapin

time: 1207

WM	WATTS/CM <sup>2</sup> /NM	WM	WATTS/CM <sup>2</sup> /NM
0375	+.3646054E-07	0700	+.4599997E-06
0400	+.6812486E-07	0750	+.1110047E-05
0425	+.9195196E-07	0800	+.1178570E-05
0450	+.1345809E-06	0850	+.1614577E-05
0475	+.1537134E-06	0900	+.8217823E-06
0500	+.1874604E-06	0950	+.4917257E-06
0525	+.3732738E-06	1000	+.5953485E-06
0550	+.7400239E-06	1050	+.5784718E-06
0550	+.7400684E-06	1100	+.4890827E-06
0575	+.2629113E-06	1150	+.3911110E-06
0600	+.3228522E-06	1200	+.7866109E-06
0605	+.2851349E-06		
0650	+.2402983E-06		
0675	+.2123405E-06		
0700	+.5631061E-06		
0700	+.5066453E-06		
0725	+.1295741E-05		
0750	+.1824316E-05		

TABLE 4.5 IRRADIANCE MEASUREMENTS OF REFLECTED ENERGY 7/29/71 (continued)

01400000 Chinquapin time: 1210

WV	WATTS/CM <sup>2</sup> /NM	WV	WATTS/CM <sup>2</sup> /NM
0275	+ .2705308E-07	0700	+ .4615383E-06
0280	+ .7610507E-07	0750	+ .1119617E-05
0285	+ .0417000E-07	0800	+ .1178575E-05
0290	+ .1370740E-06	0850	+ .1012677E-05
0295	+ .1450007E-06	0900	+ .8217883E-06
0300	+ .1009036E-06	0950	+ .4060976E-06
0305	+ .3250760E-07	1000	+ .5632754E-06
0310	+ .2230002E-06	1050	+ .5770830E-06
0315	+ .2202031E-06	1100	+ .2090760E-06
0320	+ .0807766E-06	1150	+ .3020770E-06
0325	+ .0074501E-06	1200	+ .0070091E-06
0330	+ .0021248E-06		
0340	+ .0000983E-06		
0375	+ .0021609E-06		
0380	+ .5712003E-06		
0385	+ .5770206E-06		
0390	+ .1225170E-06		
0395	+ .1016000E-06		

01610000 Manzanita time: 1223

WV	WATTS/CM <sup>2</sup> /NM	WV	WATTS/CM <sup>2</sup> /NM
0275	+ .2262301E-07	0700	+ .3700000E-06
0280	+ .7000190E-07	0750	+ .7000000E-06
0285	+ .1000000E-07	0800	+ .7000000E-06
0290	+ .1500000E-07	0850	+ .2000000E-06
0295	+ .1000000E-07	0900	+ .2000000E-06
0300	+ .1000000E-07	0950	+ .2000000E-06
0305	+ .0700000E-07	1000	+ .3700000E-06
0310	+ .0100000E-07	1050	+ .0700000E-06
0315	+ .0100000E-07	1100	+ .3500000E-06
0320	+ .0100000E-07	1150	+ .3000000E-06
0325	+ .0000000E-07	1200	+ .0000000E-06
0330	+ .0000000E-07		
0335	+ .0000000E-07		
0340	+ .0000000E-07		
0345	+ .0000000E-07		
0350	+ .0000000E-07		
0355	+ .0000000E-07		
0360	+ .0000000E-07		
0365	+ .0000000E-07		
0370	+ .0000000E-07		
0375	+ .0000000E-07		
0380	+ .0000000E-07		
0385	+ .0000000E-07		
0390	+ .0000000E-07		
0395	+ .0000000E-07		

TABLE 4.5 IRRADIANCE MEASUREMENTS OF REFLECTED ENERGY 7/29/71 (continued)


01600000

Manzanita

time: 1228

NM	WATTS/CM <sup>2</sup> /NM	NM	WATTS/CM <sup>2</sup> /NM
0375	+.4405543E-07	0700	+.3969229E-06
0400	+.4213937E-07	0750	+.7425338E-06
0425	+.1101026E-06	0800	+.7771426E-06
0450	+.1693113E-06	0850	+.6180757E-06
0475	+.1710875E-06	0900	+.5049504E-06
0500	+.1282601E-06	0950	+.3347516E-06
0525	+.2205537E-06	1000	+.3777775E-06
0550	+.3241973E-06	1050	+.3777776E-06
0575	+.3213177E-06	1100	+.3568305E-06
0600	+.2905028E-06	1150	+.3407406E-06
0625	+.2286292E-06	1200	+.8610380E-06
0650	+.2246344E-06		
0675	+.2514923E-06		
0700	+.2241629E-06		
0725	+.4584715E-06		
0750	+.4516129E-06		
0775	+.2970295E-06		
0800	+.1193717E-05		

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1162100

Manzanita

time: 1232

NM	WATTS/CM <sup>2</sup> /NM	NM	WATTS/CM <sup>2</sup> /NM
0375	+.4434967E-07	0700	+.3938460E-06
0400	+.2385260E-07	0750	+.7540667E-06
0425	+.1111300E-06	0800	+.7714283E-06
0450	+.1676646E-06	0850	+.6239066E-06
0475	+.1724137E-06	0900	+.4999999E-06
0500	+.2013933E-06	0950	+.3352243E-06
0525	+.2244625E-06	1000	+.3803614E-06
0550	+.3320272E-06	1050	+.3840276E-06
0575	+.3237670E-06	1100	+.3456017E-06
0600	+.2905028E-06	1150	+.3377777E-06
0625	+.2283255E-06	1200	+.8652722E-06
0650	+.2273872E-06		
0675	+.2432833E-06		
0700	+.2270741E-06		
0725	+.2485048E-06		
0750	+.4617097E-06		
0775	+.2851485E-06		
0800	+.1133245E-05		

TABLE 4.5 IRRADIANCE MEASUREMENTS OF REFLECTED ENERGY 7/29/71 (continued)

01640000 Huckleberry Oak time: 1245

NM	WATTS/CM <sup>2</sup> /NM	NM	WATTS/CM <sup>2</sup> /NM
0375	+.2942429E-07	0700	+.4323073E-06
0400	+.5959883E-07	0750	+.9464114E-06
0425	+.9143829E-07	0800	+.9000003E-06
0450	+.1431137E-06	0850	+.7755106E-06
0475	+.1525198E-06	0900	+.6287133E-06
0500	+.2001267E-06	0950	+.4156026E-06
0525	+.3622149E-06	1000	+.4868214E-06
0550	+.4463587E-06	1050	+.4673609E-06
0550	+.4434931E-06	1100	+.4242044E-06
0575	+.3709498E-06	1150	+.3851851E-06
0600	+.3105022E-06	1200	+.8451879E-06
0625	+.3022521E-06		
0650	+.2470147E-06		
0675	+.2183405E-06		
0700	+.5581393E-06		
0700	+.5670629E-06		
0725	+.1198019E-05		
0750	+.1689354E-05		

01650000 Huckleberry Oak time: 1249

NM	WATTS/CM <sup>2</sup> /NM	NM	WATTS/CM <sup>2</sup> /NM
0375	+.3006396E-07	0700	+.4215381E-06
0400	+.6189106E-07	0750	+.9215313E-06
0425	+.9263694E-07	0800	+.8857142E-06
0450	+.1440119E-06	0850	+.7696795E-06
0475	+.1511936E-06	0900	+.6287133E-06
0500	+.1988601E-06	0950	+.4179667E-06
0525	+.3583061E-06	1000	+.4847542E-06
0550	+.4432263E-06	1050	+.4729165E-06
0550	+.4366438E-06	1100	+.4204613E-06
0575	+.3597766E-06	1150	+.3822221E-06
0600	+.3013698E-06	1200	+.8284515E-06
0625	+.2999998E-06		
0650	+.2402983E-06		
0675	+.2139737E-06		
0700	+.5481725E-06		
0700	+.5500850E-06		
0725	+.1227721E-05		
0750	+.1664921E-05		

TABLE 4.5 IRRADIANCE MEASUREMENTS OF REFLECTED ENERGY 7/29/71 (continued)

01660000 Huckleberry Oak time: 1252

NM	WATTS/CM <sup>2</sup> /NM	NM	WATTS/CM <sup>2</sup> /NM
0375	+.2935073E-07	0700	+.4415382E-06
0400	+.6112697E-07	0750	+.9444975E-06
0425	+.9195196E-07	0800	+.8857142E-06
0450	+.1408682E-06	0850	+.7696795E-06
0475	+.1472148E-06	0900	+.6237624E-06
0500	+.1925269E-06	0950	+.4179667E-06
0525	+.3583061E-06	1000	+.4857878E-06
0550	+.4400939E-06	1050	+.4645830E-06
0550	+.4383561E-06	1100	+.4304427E-06
0575	+.3664805E-06	1150	+.3762962E-06
0600	+.3044130E-06	1200	+.8451879E-06
0625	+.3040530E-06		
0650	+.2522387E-06		
0675	+.2096069E-06		
0700	+.5514948E-06		
0700	+.5534805E-06		
0725	+.1188019E-05		
0750	+.1570681E-05		

01670000 Tobaccobrush time: 1303

NM	WATTS/CM <sup>2</sup> /NM	NM	WATTS/CM <sup>2</sup> /NM
0375	+.3859273E-07	0700	+.3753843E-06
0400	+.6895887E-07	0750	+.8899521E-06
0425	+.9383553E-07	0800	+.8357143E-06
0450	+.1351796E-06	0850	+.7113707E-06
0475	+.1286472E-06	0900	+.5792078E-06
0500	+.1621279E-06	0950	+.3886523E-06
0525	+.2983713E-06	1000	+.4542633E-06
0550	+.3617854E-06	1050	+.4374997E-06
0550	+.3595889E-06	1100	+.3980034E-06
0575	+.2793297E-06	1150	+.3674073E-06
0600	+.2566208E-06	1200	+.8368200E-06
0625	+.2207205E-06		
0650	+.1813431E-06		
0675	+.1601163E-06		
0700	+.4052490E-06		
0700	+.4346351E-06		
0725	+.1118311E-05		
0750	+.1595113E-05		

TABLE 4.5 IRRADIANCE MEASUREMENTS OF REFLECTED ENERGY 7/29/71 (continued)

01680000 Tobaccobrush time: 1305

NM	WATTS/CM <sup>2</sup> /NM	NM	WATTS/CM <sup>2</sup> /NM
0375	+.3603410E-07	0700	+.3446152E-06
0400	+.6991404E-07	0750	+.8794260E-06
0425	+.9297937E-07	0800	+.8285719E-06
0450	+.1326346E-06	0850	+.7055395E-06
0475	+.1273210E-06	0900	+.5742574E-06
0500	+.1533281E-06	0950	+.3881794E-06
0525	+.2957654E-06	1000	+.4496121E-06
0550	+.3633516E-06	1050	+.4333330E-06
0550	+.3613013E-06	1100	+.3855268E-06
0575	+.2837990E-06	1150	+.3614814E-06
0600	+.2614915E-06	1200	+.9397488E-06
0625	+.2238737E-06		
0650	+.1883058E-06		
0675	+.1542940E-06		
0700	+.4252490E-06		
0700	+.4312394E-06		
0725	+.1123712E-05		
0750	+.1539267E-05		

01690000 Tobaccobrush time: 1308

NM	WATTS/CM <sup>2</sup> /NM	NM	WATTS/CM <sup>2</sup> /NM
0375	+.3624733E-07	0700	+.3523076E-07
0400	+.6914991E-07	0750	+.8851671E-06
0425	+.9400683E-07	0800	+.8071428E-06
0450	+.1348802E-06	0850	+.7055395E-06
0475	+.1452254E-06	0900	+.5742574E-06
0500	+.1608613E-06	0950	+.3829785E-06
0525	+.2944625E-06	1000	+.4485785E-06
0550	+.3586531E-06	1050	+.4305553E-06
0550	+.3613013E-06	1100	+.3830315E-06
0575	+.2770950E-06	1150	+.3555554E-06
0600	+.2560120E-06	1200	+.9355646E-06
0625	+.2211710E-06		
0650	+.1853206E-06		
0675	+.1572051E-06		
0700	+.4219267E-06		
0700	+.4380306E-06		
0725	+.1089108E-05		
0750	+.1563699E-05		

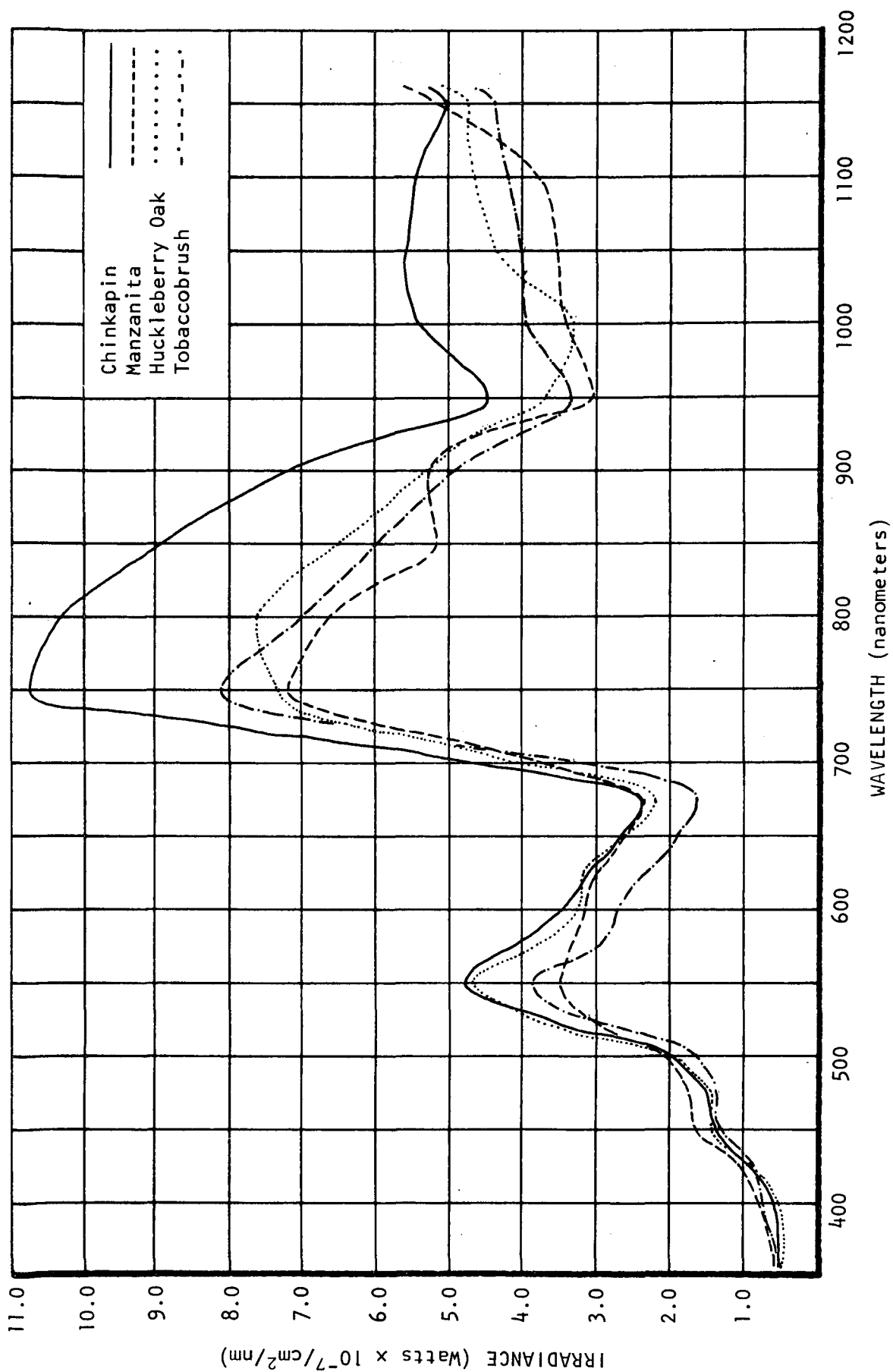


Figure 4.33 Energy reflected from four plant species in the Spanish Peak brushfields.



TABLE 4.6 RANKING OF STANDARDIZED IRRADIANCE MEANS BY WAVELENGTH  
ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST - .95 PROTECTION LEVEL

Wavelength--375nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	HUCKLE	.5153	3	.6930
2	TOBACC	.5373	3	.0335
3	MANZAN	.6773	3	.0265
4	CHINKA	1.3210	2	.9800

Wavelength--400nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	HUCKLE	.59600	3	.0203
2	TOBACC	.67900	3	.0381
3	CHINKA	.68350	2	.0233
4	MANZAN	.79733	3	.0283

Wavelength--425nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	.9217	3	.0388
2	HUCKLE	.9303	3	.0404
3	CHINKA	.9700	2	.0566
4	MANZAN	1.0633	3	.0379

TABLE 4.6 RANKING OF STANDARDIZED IRRADIANCE MEANS BY WAVELENGTH  
ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST - .95 PROTECTION LEVEL (continued)

Wavelength--450nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	1.3200	3	.0566
2	CHINKA	1.4050	2	.0495
3	HUCKLE	1.4167	3	.0382
4	MANZAN	1.6900	3	.0529

Wavelength--475nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	1.3400	3	.0990
2	HUCKLE	1.5300	3	.0566
3	CHINKA	1.5600	2	.0707
4	MANZAN	1.7300	3	.0265

Wavelength--500 nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	1.6400	3	.0529
2	CHINKA	2.0000	2	.0141
3	HUCKLE	2.0267	3	.0428
4	MANZAN	2.0500	3	.0458

TABLE 4.6 RANKING OF STANDARDIZED IRRADIANCE MEANS BY WAVELENGTH  
ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST - .95 PROTECTION LEVEL (continued)

Wavelength--525nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	3.1000	3	.1544
2	MANZAN	3.1033	3	.1501
3	CHINKA	3.7650	2	.0354
4	HUCKLE	3.8167	3	.0382

Wavelength--550nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	MANZAN	3.4800	3	.0954
2	TOBACC	3.8400	3	.0990
3	HUCKLE	4.7633	3	.0382
4	CHINKA	4.8850	2	.0212

Wavelength--575nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	2.9200	3	.0990
2	MANZAN	3.3400	3	.0854
3	HUCKLE	3.8200	3	.0632
4	CHINKA	3.9000	2	.0424

TABLE 4.6 RANKING OF STANDARDIZED IRRADIANCE MEANS BY WAVELENGTH  
ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST - .95 PROTECTION LEVEL (continued)

Wavelength--600nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	2.7267	3	.0638
2	MANZAN	3.1667	3	.0943
3	HUCKLE	3.2700	3	.1146
4	CHINKA	3.4650	2	.1485

Wavelength--625nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	2.3333	3	.0673
2	MANZAN	3.0100	3	.0624
3	CHINKA	3.1700	2	.0283
4	HUCKLE	3.2100	3	.0283

Wavelength--650nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	1.9600	3	.0721
2	HUCKLE	2.6167	3	.0739
3	MANZAN	2.6300	3	.0624
4	CHINKA	2.6650	2	.0495

TABLE 4.6 RANKING OF STANDARDIZED IRRADIANCE MEANS BY WAVELENGTH  
ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST - .95 PROTECTION LEVEL (continued)

Wavelength--675nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	1.6400	3	.0548
2	HUCKLE	2.2533	3	.0493
3	MANZAN	2.4000	3	.0458
4	CHINKA	2.4100	2	.0283

Wavelength--700nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	3.3800	3	.1874
2	MANZAN	3.7267	3	.1021
3	HUCKLE	4.0900	3	.1034
4	CHINKA	4.5400	2	.0566

Wavelength--725nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	MANZAN	9.050	3	.1735
2	TOBACC	10.117	3	.2931
3	HUCKLE	11.167	3	.1528
4	CHINKA	13.700	2	.1414

TABLE 4.6 RANKING OF STANDARDIZED IRRADIANCE MEANS BY WAVELENGTH  
 ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST - .95 PROTECTION LEVEL (continued)

Wavelength--750nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	MANZAN	7.213	3	.3459
2	HUCKLE	7.357	3	1.2790
3	TOBACC	8.120	3	.3616
4	CHINKA	10.850	2	.3536

Wavelength--800nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	MANZAN	6.690	3	.0361
2	TOBACC	7.090	3	.2131
3	HUCKLE	7.663	3	.1401
4	CHINKA	10.400	2	.0000

Wavelength--850nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	MANZAN	5.2533	3	.0451
2	TOBACC	6.0167	3	.0535
3	HUCKLE	6.5567	3	.1283
4	CHINKA	8.9250	2	.1768

TABLE 4.6 RANKING OF STANDARDIZED IRRADIANCE MEANS BY WAVELENGTH  
 ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST - .95 PROTECTION LEVEL (continued)

Wavelength--900nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	4.9133	3	1.9113
2	HUCKLE	5.3467	3	.1075
3	MANZAN	5.3933	3	1.9111
4	CHINKA	7.3250	2	.1485

Wavelength--950nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	MANZAN	3.1133	3	.2581
2	TOBACC	3.3900	3	.2595
3	HUCKLE	3.7233	3	.0275
4	CHINKA	4.5050	2	.0354

Wavelength--1000nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	MANZAN	3.4933	3	.2312
2	TOBACC	3.9900	3	.2327
3	HUCKLE	4.3000	3	.1254
4	CHINKA	5.4050	2	.1768

TABLE 4.6 RANKING OF STANDARDIZED IRRADIANCE MEANS BY WAVELENGTH  
 ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST - .95 PROTECTION LEVEL (continued)

Wavelength--1050nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	MANZAN	3.5900	3	.0600
2	TOBACC	4.0200	3	.0938
3	HUCKLE	4.3700	3	.0700
4	CHINKA	5.6100	2	.0849

Wavelength--1100nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	MANZAN	3.8567	3	.0611
2	TOBACC	4.2233	3	.1621
3	HUCKLE	4.6600	3	.0783
4	CHINKA	5.5750	2	.0778

Wavelength--1150nm

TREATMENT MEANS IN RANKED ORDER

RANK	LABEL	MEAN	NUMBER OF REPLICATIONS	STANDARD DEVIATION
1	TOBACC	4.4400	3	1.8626
2	HUCKLE	4.7300	3	.0592
3	CHINKA	5.0200	2	.0283
4	MANZAN	5.2367	3	1.8570



TABLE 4.6 RANKING OF STANDARDIZED IRRADIANCE MEANS BY WAVELENGTH  
 ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST - .95 PROTECTION LEVEL (continued)

Wavelength--1200nm

TREATMENT MEANS IN RANKEO ORDER

RANK	LABEL	MEAN	NUMBER REPLICATIONS	CF	STANDARD DEVIATION
1	MANZAN	9.047	3		5.2022
2	HUCKLE	11.733	3		.7911
3	CHINKA	12.350	2		1.0607
4	TOBACC	12.600	3		5.2605

irradiance in Watts  $\times 10^{-7}/\text{cm}^2/\text{nm}$ . The mean of the energy reflected by any species is considered to be not significantly different from the mean of another species if the rankings of the two are preceded by the same vertical line. Any two means not preceded by the same line are considered to be different. This statistical analysis was made at the 95% protection level.

As an example of the interpretation of the analysis, let us consider the data for wavelength 550nm. Manzanita is different from the other species and ranks as number one, i.e., reflects the least amount of light at 550nm. Tobaccobrush is also different from the other species and ranks number two; it reflects more light at 550nm than manzanita, but less than huckleberry oak and chinquapin which are statistically inseparable in the amount of light they reflect at 550nm. Huckleberry oak and cinquapin as a sub-set, however, reflect significantly more light at 550nm than either manzanita or tobaccobrush.

From examination of standardized data such as are presented here it is possible to predict what parts of the spectrum are most useful for discriminating between the plant species. The information would be useful for planning film-filter combinations for aircraft photographic missions where knowledge of species composition within a vegetative type is desired.

#### 4.5.2 Future Proposed Research

Future work is planned in two areas--data acquisition and data analysis. FRSL is scheduled to take delivery in February 1972 of a van type truck which will be outfitted to transport the Spectral

Characteristics Unit equipment and to provide a platform for many of the spectral measurements. A description of the vehicle outfitting and platform configuration will be given in future reports. The use of this vehicle should make field measurements more efficient and provide a safer environment for transportation of the equipment from site to site.

Tentative plans are being made to fabricate an attachment for the spectroradiometers which are used to measure reflected energy so that these instruments can also be used to measure the incident energy. The use would involve only removing the restrictive cone and attaching the fabricated optics in its place. Incident energy measurements would be accomplished from the same setup used to measure reflected energy. With this arrangement measurements of incident energy could be easily interspersed with the measurements of reflected energy using the same spectroradiometer. In addition to simplifying the problems inherent in calibration between different types of instruments, the data from incident and reflected measurements would be recorded on the same data tape and in the same format, making data retrieval and analysis much easier.

New techniques will be investigated for data analysis. In particular, software "forms" must be prepared to facilitate entry of recorded spectral data into various "canned" statistical analysis routines.

In the coming year we hope to be able not only to determine those spectral bands most likely to provide maximum chance for discrimination

between features of interest, but also to run an operational test and determine the degree of improvement which can be expected over conventional multiband photography, i.e., broadband blue, green, red and infrared filters.

#### 4.6 REPORT OF THE TRAINING UNIT

When the forestry remote sensing research program at the University of California was restructured into its current configuration consisting of "functional units", it was recognized that possibly the strongest contribution the Laboratory could make would be through training programs which would serve to disseminate information about our Laboratory's research findings to the potential users of modern remote sensing techniques. Not only is a University atmosphere conducive to such activities, but also members of the Laboratory staff are professional educators experienced at giving lectures, seminars, workshops and short courses. Consequently, a fifth functional unit, the Training Unit, was created and immediately became active.

It is very apparent that the rate of remote sensing technique development is increasing at a much faster pace than is the rate at which these same techniques are being put to some practical use. On the one hand, research scientists and engineers are actively engaged in sensor development and applications research, while on the other hand, earth resource managers and inventory specialists struggle to keep pace with new technology and to relate it to informational requirements within their own disciplines. Unfortunately, those burdened with the responsibility of managing the world's earth resources often are unable to

comprehend rapid advances in the field of remote sensing. This is particularly true for advances which employ high altitude aircraft and spacecraft sensor systems and automatic image classification and data processing techniques. Yet it is they who must ultimately decide whether the end product of this sophistication is meaningful.

Considering that ERTS-A will be launched within the year and that the high-flight U-2 aircraft project already has been implemented, it becomes increasingly important to bridge this widening communication gap between remote sensing specialists and potential "users", especially resource managers. Thus the Training Unit within the Forestry Remote Sensing Laboratory has engaged in a number of activities which draw on the teaching experience and knowledge of members of the Laboratory staff. These training activities entail a consideration of virtually all phases of remote sensing data acquisition and analysis. Such activities have been designed to (1) provide a means of interchange between our research staff and "user" groups and (2) impart to resource specialists information on state-of-the-art remote sensing.

#### 4.6.1 Current Activities

The diagram presented in Figure 4.34 lists five specific tasks which Training Unit personnel are currently performing. These include maintaining library facilities, disseminating research findings and training remote sensing specialists in adequate numbers for staffing various future earth resources survey programs.

The documents and film libraries at the FRSL are being maintained and updated for use by our staff, students and Laboratory visitors. The remote sensing documents library is, to our knowledge, the only one of

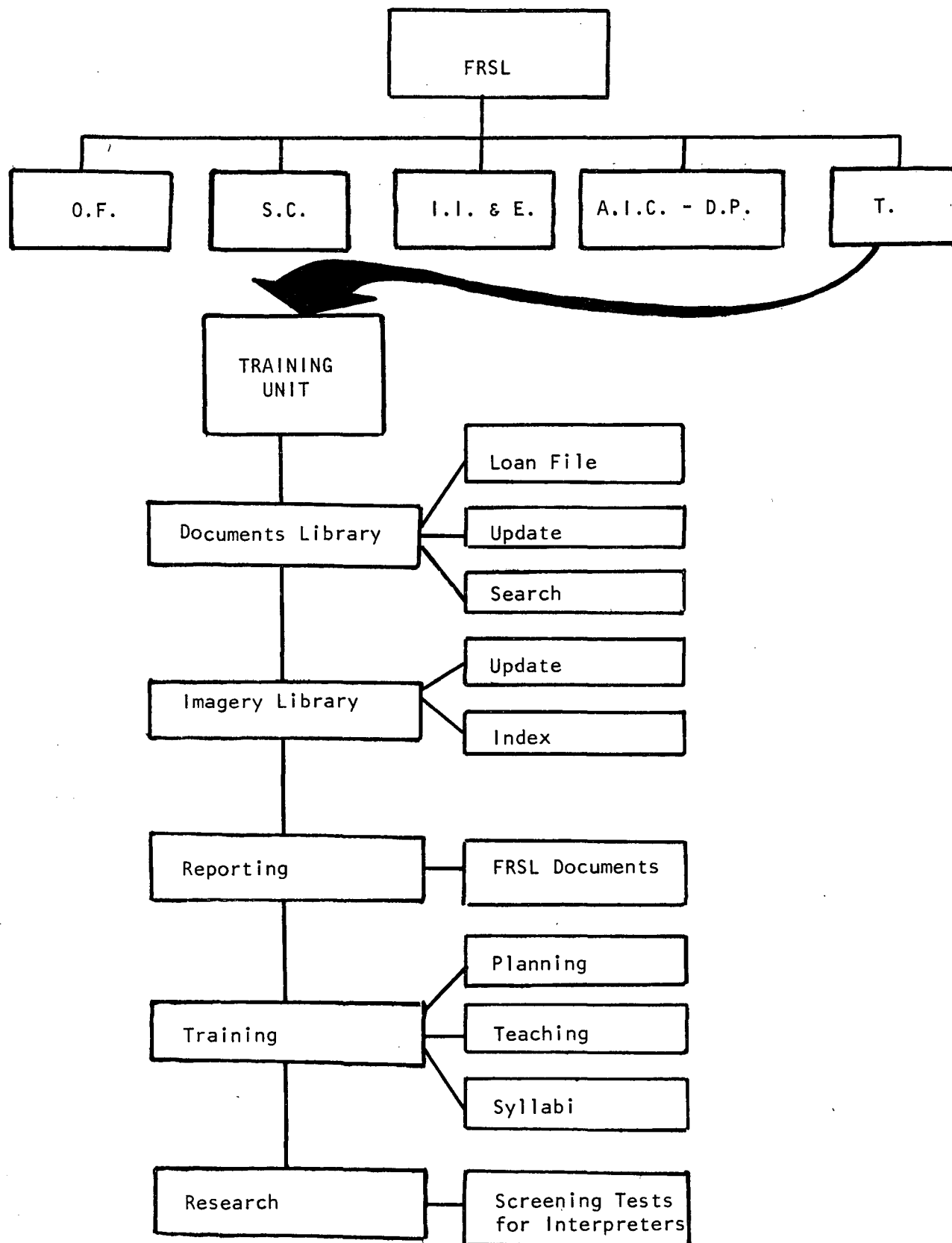


Figure 4.34. The diagram above depicts the functional tasks performed by the Training Unit within the Forestry Remote Sensing Laboratory.

its kind located in the far-western U.S. and now contains over 3400 items. Computerized searching techniques (author and/or key word) can be employed to quickly and efficiently locate documents, and a loan file is maintained whereby anyone interested in any particular item, including a fully illustrated copy of any FRSL report, may obtain it.

Likewise, the remote sensing imagery at the FRSL, which is indexed in a manner similar to that used for all NASA imagery at NASA/MSC (U.S. Army Map Service UTM grid system) is available for analysis at the Laboratory. We have found that the imagery library, which contains data obtained from earth orbiting satellites (Tiros, Nimbus, Gemini, and Apollo), NASA Earth Resources Program aircraft (Convair 240, Lockheed P3A, Lockheed C130 and RB57), government agencies (Agricultural Stabilization and Conservation Service, Geological Survey, Forest Service, etc.), and private contractors, can provide a means for review of imagery by scientists prior to requesting reproductions from NASA or other agencies. In addition, we are prepared to index, and thus incorporate into this library facility, the simulated ERTS data currently being procured over the various western U.S. regional test sites by the U-2 aircraft stationed at NASA-Ames.

In addition, a major responsibility of the Training Unit is to disseminate the research findings derived by the FRSL staff. Fully illustrated copies of all NASA funded forestry reports, special reports, training syllabi and field tour guides prepared by the FRSL staff are available in the documents library loan file. Furthermore, in the case of most FRSL reports, more than 200 copies are distributed to both

national and international library facilities, research groups and user agencies.

In reference to training, we are pursuing a vigorous program involving lectures, short courses, workshops, guided field tours of NASA test sites and formal training courses. We feel that virtually all remote sensing training programs currently being offered are merely "appreciation courses", i.e., those designed to convey to the attendee that remote sensing techniques offer a powerful means of making accurate, timely, economical inventories of earth resources. While there may be a continuing need for these courses to be presented to various top-level "decision-makers", the major need is to train the actual "doers". Mere appreciation courses definitely will not prepare them to accomplish the all-important task of making operational inventories. Instead, they need to receive rigorous training in how to produce, through an analysis of remote sensing data, a survey of earth resources of the type that will meet the specific informational needs of the resource manager.

As in other Forestry Remote Sensing Laboratory training exercises conducted thus far, all future programs will make maximum use of the concept of "learning by doing". Consistent with this concept, actual rather than hypothetical problems are emphasized. These problems are centered around the inventory of earth resources at NASA test sites, one of which (the San Pablo Reservoir Test Site) is only eight miles from our classroom facilities at the University of California. Training films, field tour manuals, and display boards based on this and other NASA test sites which our group has studied during the past seven years have been successfully used for training in the past and are available for future



programs. These training materials illustrate various data acquisition and analysis techniques with emphasis on both the gathering of "ground truth" data and the extraction of information from remote sensing imagery. More specifically, during these training programs we attempt to disseminate information on the following subjects: (1) specific user requirements for earth resource information; (2) basic matter and energy relationships; (3) remote sensing capabilities in various parts of the electromagnetic spectrum; (4) sampling techniques including techniques for the acquisition of ground truth; (5) photo interpretation equipment and techniques; (6) image enhancement techniques; (7) automatic data processing techniques; and (8) techniques for optimizing the interaction between those who provide earth resource inventories and those who use them in the management of earth resources.

It should be noted that the FRSL staff just recently presented a comprehensive 5-week training course. The purpose of the course was to train approximately 30 resource managers and inventory specialists affiliated with the U.S. Department of Interior to inventory earth resources (i.e., land, water, mineral, vegetation, and cultural) with the aid of remote sensing. Maximum emphasis was placed on the use of current state-of-the-art remote sensing capabilities from aircraft and spacecraft, including those soon to be tested in the ERTS-A and Skylab programs.

In addition, members of the Training Unit are engaged in several research efforts which relate directly to training people to become proficient in applying remote sensing techniques to resource inventory problems. For example, the testing of a person's level of experience, degree of motivation, and mental and visual acuity constitutes an important

first step leading to proficiency in performing resource surveys using manual interpretation techniques. Such testing often leads to adequate screening of candidate personnel and, thus, to the elimination of poor prospects prior to initiating an operational project. We are currently in the process of reviewing the literature relative to this subject, collecting examples of screening tests previously prepared by other investigators and making a series of our own tests. These tests relate directly to the FRSL projects involving applications of high-flight, multiband-multidate imagery to agricultural and forestry environmental problems. Once the screening tests are perfected and proven to be effective, they will be valuable instructional material for any forthcoming training course given by the FRSL staff.

#### 4.6.2 Future Activities

Final arrangements are being made regarding FRSL participation in the forthcoming training course sponsored by the NASA Ames Research Center. The course will be given over a two-week period to individuals representing state of California user agencies. The purpose of this course is to familiarize state personnel with modern remote sensing techniques and to prepare them for the imminent task of analyzing with U-2 and ERTS imagery. The cooperative nature of the course (which brings together the special talents of individuals from the state, NASA and University of California) should lead to a successful training program. Members of FRSL will aid in presenting the course and will give instruction on (1) introduction and theory of remote sensing and (2) applications of remote sensing to problems dealing with vegetative resources.

Lastly, it is important to note that in addition to carrying on

those activities listed in the previous section, the Training Unit at the FRSL will act as a focal point for non-grant cooperators (e.g., California Agricultural Extension Service, Bureau of Land Management) during the U-2 and ERTS-A experiments. We will provide copies of imagery in our files to the various investigators and make available to them data analysis equipment and technical assistance.

N72-20348

## Chapter 5

### RIVER MEANDER STUDIES

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As discussed in detail in our earlier progress reports, we are undertaking a basic study of river meander patterns, the results of which, we believe, would be of benefit to hydrologic development in two specific areas. First, the study which we have outlined should result in new criteria by which the stability of a meander pattern at arbitrary discharge may be examined. Such an examination would then be used as part of the evidence in the decision as to whether existing river control systems -- levees, check dams, and diversion areas -- are adequate at some assumed flood stage, or whether additional control facilities must be built. It is already clear that at some flood stage, rivers produce rapid, often disastrous, alterations in their meander patterns, and it is an objective of our study to see if such alterations can be anticipated. The Feather and Colorado Rivers are appropriate for attempted application of this technique, although part of the basic study which we are undertaking will require data from an undeveloped river to avoid the additional complication which river development adds to the problem. A second anticipated benefit of our study will be in the area of preliminary regional planning.

One of the now apparent shortcomings of many previous development programs is the limited regional scale to which the preliminary studies

have been applied. The trend in recent years has been toward more extensive alterations in natural river flow patterns over large areas, which may involve more than one important drainage basin. As important and expensive as the Feather River Water Project in California has become, it is dwarfed by proposals already being advanced to divert large volumes of water from the Columbia River basin to the Southwest.

It is the intent of our research to develop a relatively simple and inexpensive technique to assess the water resources of large, relatively undeveloped geographical areas in order that comprehensive water development plans may be prepared with less expenditure of money and time for the collection of data on the earth surface. We are seeking to determine whether it will be possible to extract data on the total discharge of a river, both past and present, from satellite television photography of river meander patterns. We expect also that this technique will yield indirect information on the average rainfall over large drainage basins, calculated by relating the flow measurements to the geographical areas involved.

Since most river drainage basins in the U.S. have already undergone substantial development, and since river discharge and rainfall data are reasonably reliable in this region, we expect the proposed technique to be of value largely in underdeveloped and poorly surveyed areas of the world. Data available in such areas as the United States will serve for the validation of the technique, which is our principal research task.

If the technique can be validated by our research, hydrologic data can be acquired for large regions at low cost, and a data base established to support a water management program for large, presently underdeveloped

geographical areas.

## 5.1 WORK PERFORMED DURING THE PERIOD COVERED BY THIS REPORT

During recent months we made substantial progress in our geomorphological investigation of a possible correlation between the stream meander power spectrum and the stream discharge frequency distribution. As we noted previously this investigation involves the following steps:

1. Selection of appropriate rivers.
2. Collection of suitable photographic coverage.
3. Collection of historical streamflow data.
4. Digitization of streamflow data.
5. Digitization of stream meander patterns.
6. Matching of individually digitized portions of meander patterns to obtain a continuous record.
7. Construction of stream discharge frequency distribution from discharge data.
8. Construction of power spectra of local river meander directions and radii of curvature.
9. Determination of relationship of meander power spectra to discharge frequency distribution.

We have now completed the first eight of these steps for the Feather River and have thus established the procedures for generating the stream discharge probability density functions and meander power spectra for other rivers.

Before we can proceed to the final step of studying the relationship between discharge spectrum and the meander spectrum we must generate

these quantities for a large number of rivers. We are presently engaged in this endeavor.

#### 5.1.1 Digitization

The digitization of river meander patterns from aerial photography is most accurately and economically accomplished through photoelectric optical scanning. The Programmable Film Reader/Recorder (PFR-3) developed by Information International Inc., Los Angeles, employs this technique and we have constructed a program for digitizing river meanders on this machine. An important condition on the digitization procedure is that we locate points at equal increments of distance along the meander curve. This condition follows from the fact that local meander direction and radius of curvature are functions of distance along the meander and the algorithms used for constructing their power spectra require that we know these quantities at equal increments of distance.

The essence of the digitization procedure is as follows (see also Figure 5.1): The initial point on the meander pattern is found by scanning along a horizontal or vertical line and measuring the density profile along the scan (line AB in Figure 5.1). The river bank, i.e., the point digitized, is defined as the location of the point of maximum gradient in the density profile (point 1). The second point is determined by an iterative process starting with a scan (line CD) parallel to the initial scan but displaced by a distance,  $s$ , from point 1. The first estimate of this point (2') is determined in the same manner as above. The distance between points 1 and 2' is then calculated and if it is not equal to the required spacing,  $s$ , plus or minus some small  $\Delta$ , another scan (line EF) is made along a line perpendicular to that line

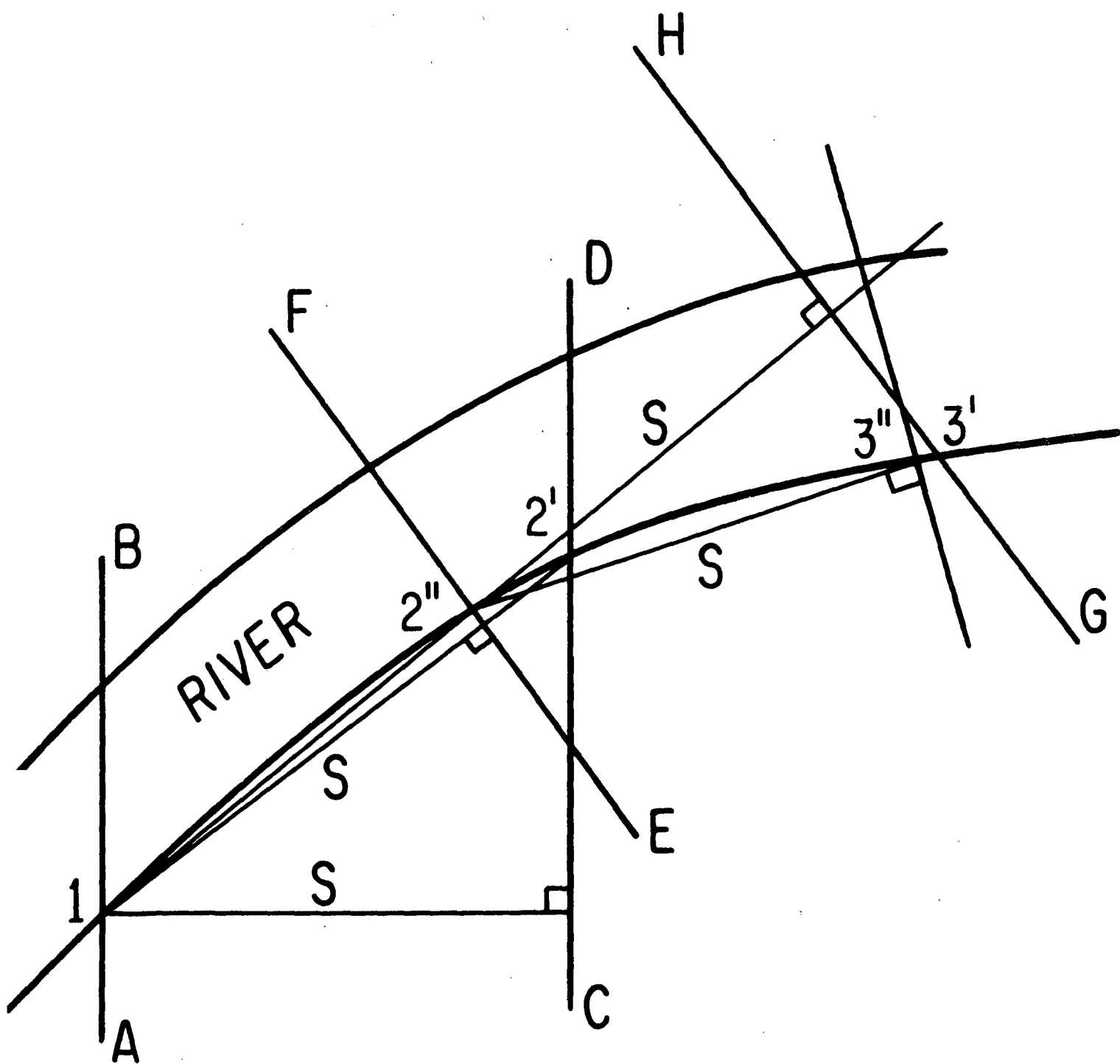


Figure 5.1. Digitization procedure.



connecting points 1 and 2' at a distance  $s$  from point 1. Point 2'' is then determined along this scan. If the distance between it and point 1 is still not within  $s \pm \Delta$ , the iterative process is repeated until convergence is obtained. Once point 2 is located, the search for point 3 begins along a scan line (GH) perpendicular to the line connecting points 1 and 2 at a distance  $s$  from point 2.

In this manner the machine proceeds along the meander curve digitizing points at equal distance increments along the curve. The process is then repeated for the other bank of the river. A computer generated plot of the digitized meander pattern of a section of the Feather River is shown as the overlay in Figure 5.2 together with the infrared photograph from which the pattern was derived. As can be seen this technique provides an accurate reproduction of the meander pattern.

As is generally the case, the photographic coverage of the river consists of a number of overlapping frames, thus this digitization procedure is repeated for each frame. The data for adjacent frames must then be matched to give a continuous digitized record of the meander pattern for each bank. Because of the large overlap between frames (roughly one-third of the data on the end of each frame overlaps with the data on the beginning of the next frame) the data sets can be uniquely matched for congruency in the overlap region. We have developed a computer program which finds the appropriate coordinate transformation, i.e., includes both translation and rotation of one frame with respect to the other. This is accomplished by considering a length of river roughly half the length of the overlap region on one frame and effectively sliding this portion of the data along the overlap portion of the adjacent



Figure 5.2. Infrared aerial photography of section of Feather River with overlay of digitized meander pattern.

frame, finding that transformation within the overlap region which minimizes the sum of the squares of the distances between matched points. Once the appropriate coordinate transformation is determined all of the data points on the second frame are transformed to the coordinate system of the first frame. The process is then repeated to match successive frames until the entire record is transformed into a single coordinate system.

The digitization and matching procedure described above has been applied to a 23 mile reach of the Feather River below the dredge tailings at Oroville to the Southern Pacific Railroad bridge north of Yuba City (Figure 5.3). A mosaic of aerial infrared photography covering this reach of the river is shown in Figure 5.4 and a Calcomp plot of the final data sets is shown in Figure 5.5 for two cases where the banks have been defined either by passage inside or outside islands and bars.

#### 5.1.2 River Meander Power Spectra

The digitization and matching procedures described above produce a set of data points (X, Y coordinates) which are equally spaced along the course of the river. A power spectral analysis of the river cannot be made directly from the X versus Y data since the river may double back upon itself making X a double valued function of Y. An equivalent representation of the river, which is single valued and thus amenable to power spectral analysis is its local direction,  $\theta$ , as a function of the distance, s, along the river's course.

The power spectral density ( $\text{deg}^2/\text{cycle per foot}$ ) for the direction  $\theta$  is computed using standard techniques for determining the autocorrelation function, smoothing, and taking the Fourier transform (e.g.,







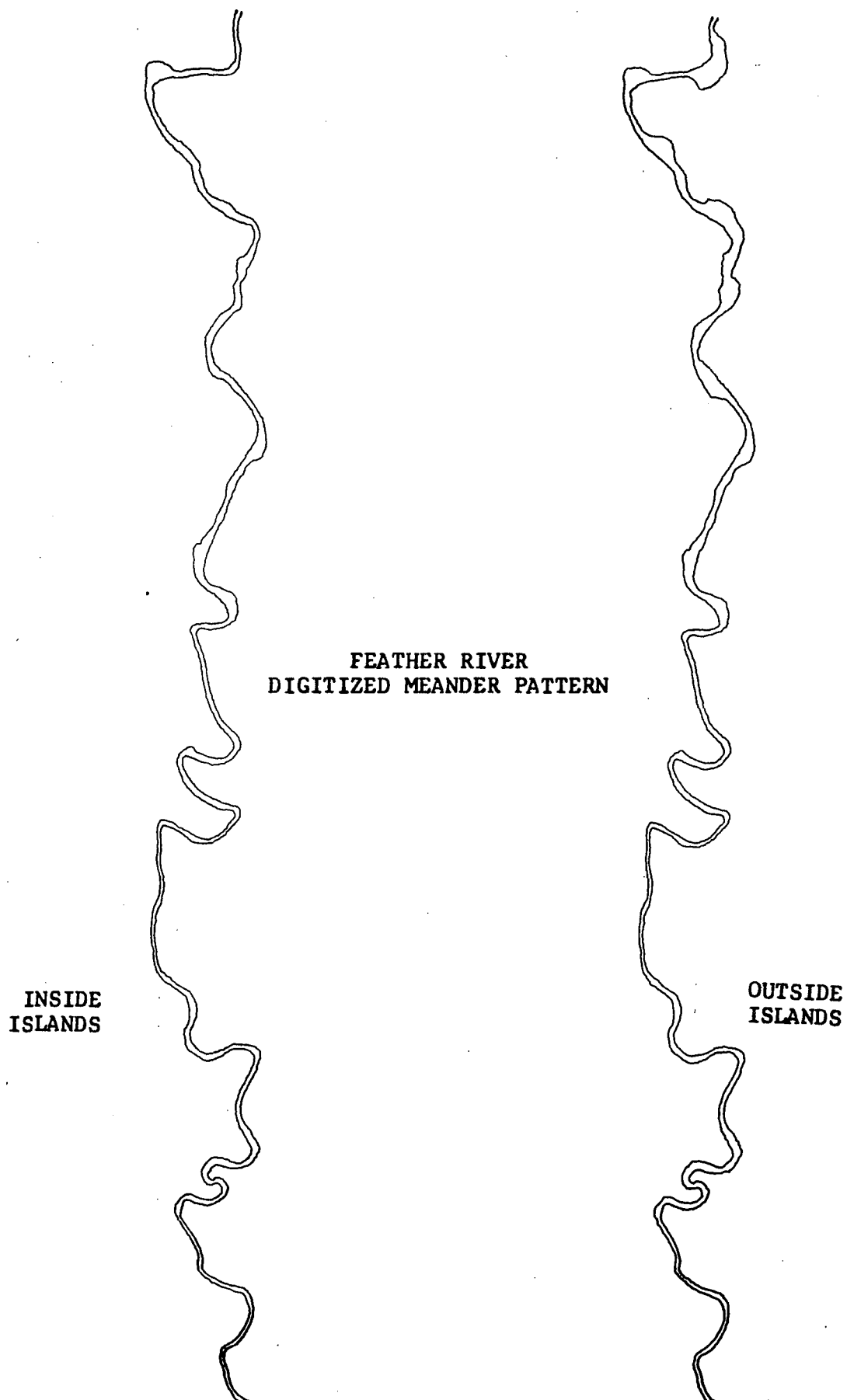


Figure 5.5. Calcomp plot of digitized meander pattern of Feather River reach with banks defined by passage inside (left) and outside (right) islands and bars.

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J. S. Bendat and A. G. Piersol, Measurement and Analysis of Random Data, John Wiley, 1966). The spectrum is analyzed for 6 degrees of freedom which gives us 80% confidence that the spectral value lies within 2.8 and 0.5 times the computed estimate.

We have applied these techniques to the reach of the Feather River described above, and the power spectral density for each bank is shown in Figure 5.6 as a function of wavelength,  $\lambda$ , measured along  $s$ . As can be seen, the meander pattern results from a broad spectral peak at wavelengths between about 5,000 and 100,000 feet. Spectral information is limited at wavelengths greater than 100,000 feet by the total length of the reach of river being analyzed. At wavelengths less than about 5,000 feet there is no coherent contribution of power to the meander pattern. From this figure and Figure 5.7 we see that there is no significant difference in the power spectra of the right and left banks or of the banks defined by passing inside or outside islands and bars.

There is a suggestion of fine structure (i.e., multiple peaks) within this broad spectral peak. Furthermore, each of these multiple peaks may be predominantly associated with separate subreaches of the river as is evident from the positions of the spectral peaks for each of the subreaches shown in Figure 5.8.

The power spectra of portions of the Feather River presented here and spectra we have obtained of reaches of other rivers proves the practicality of our procedure and demonstrates that such spectra contain significant quantitative information on meander patterns, such as the wavelength of spectral peaks, which may ultimately be correlated with the discharge at peaks in the discharge probability density function.

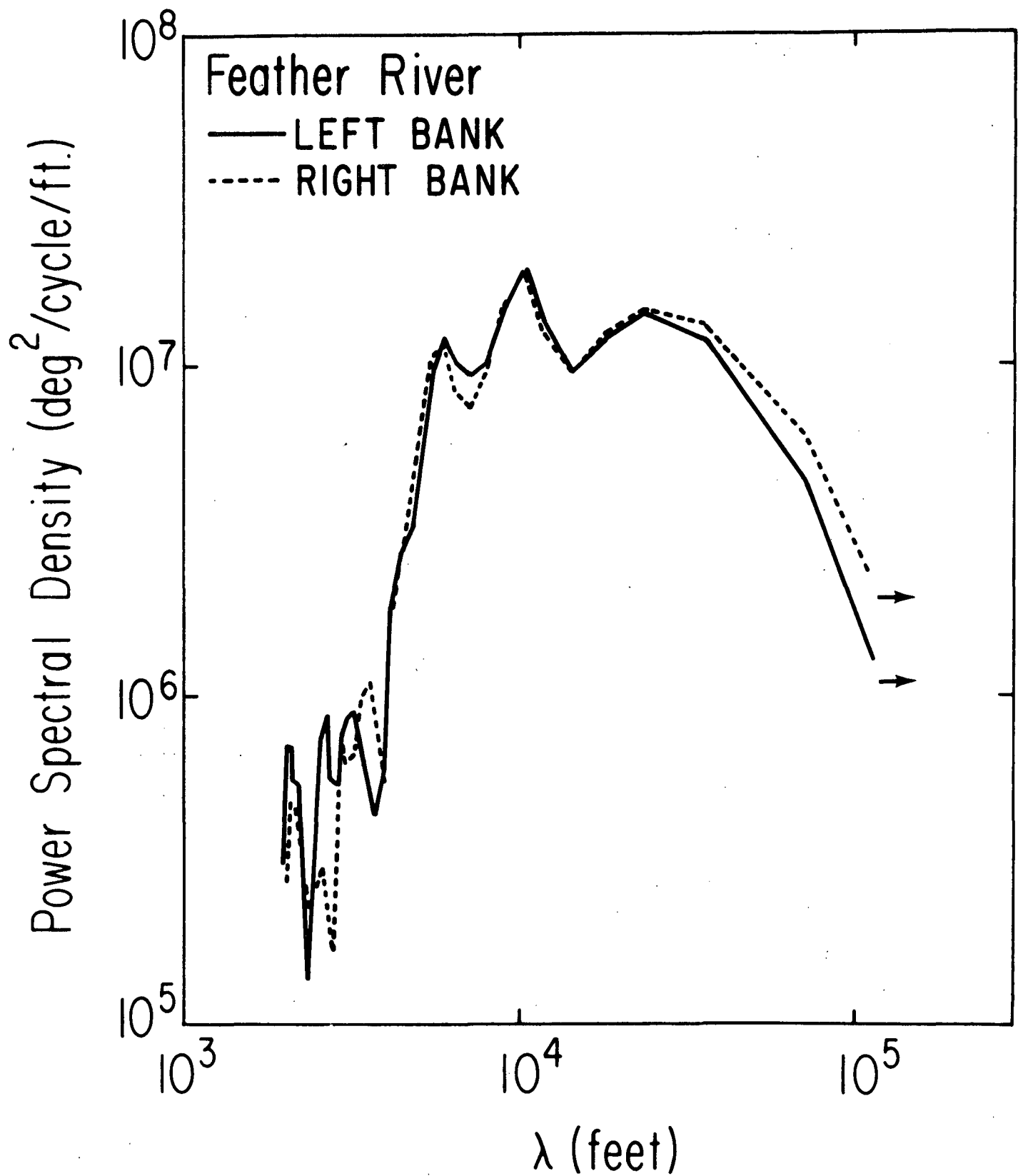


Figure 5.6. Power spectral density for each bank of Feather River reach as a function of meander wavelength,  $\lambda$ , measured along s.



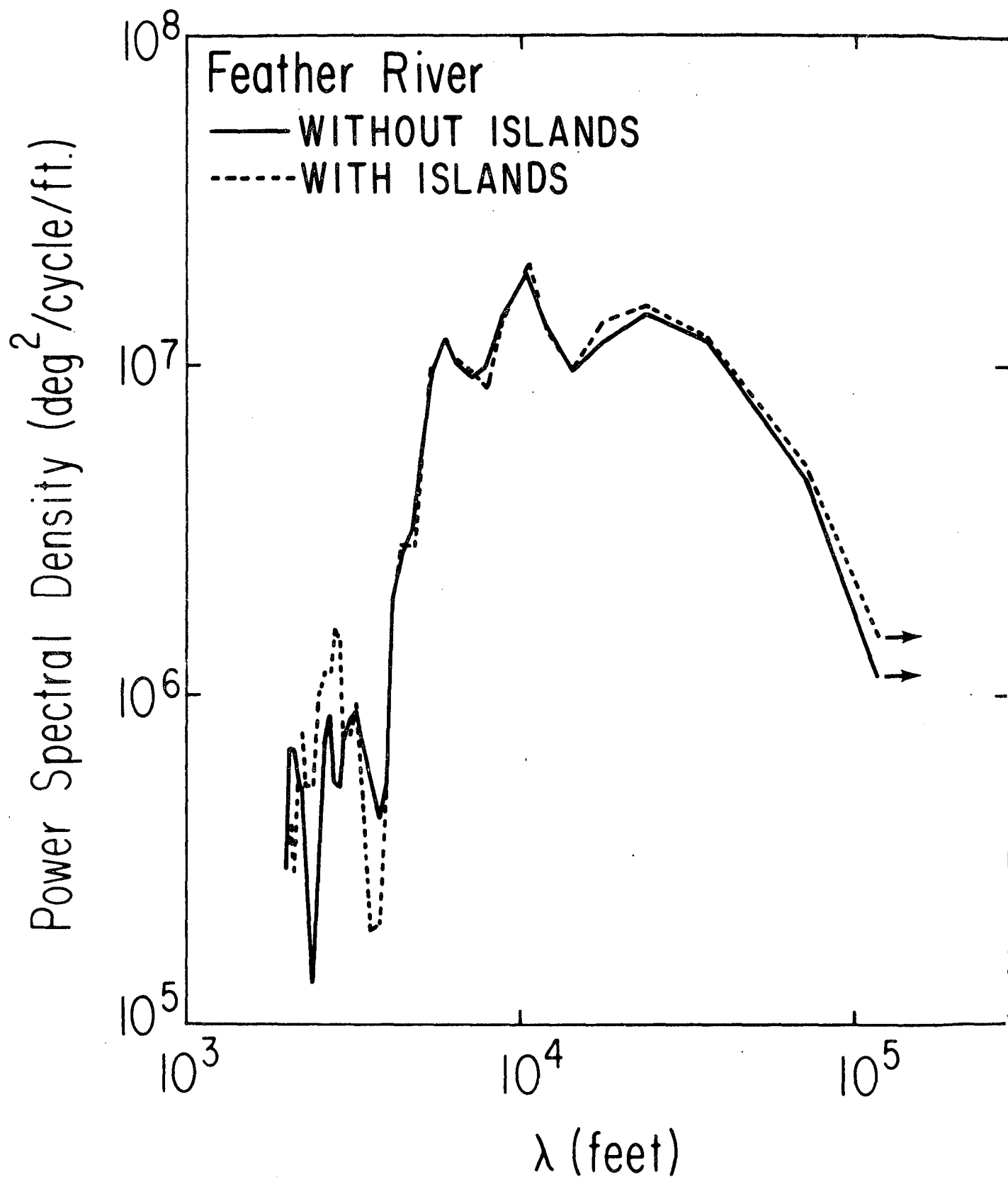


Figure 5.7. Power spectral density of Feather River reach for banks defined by passage inside (without) and outside (within) islands and bars.

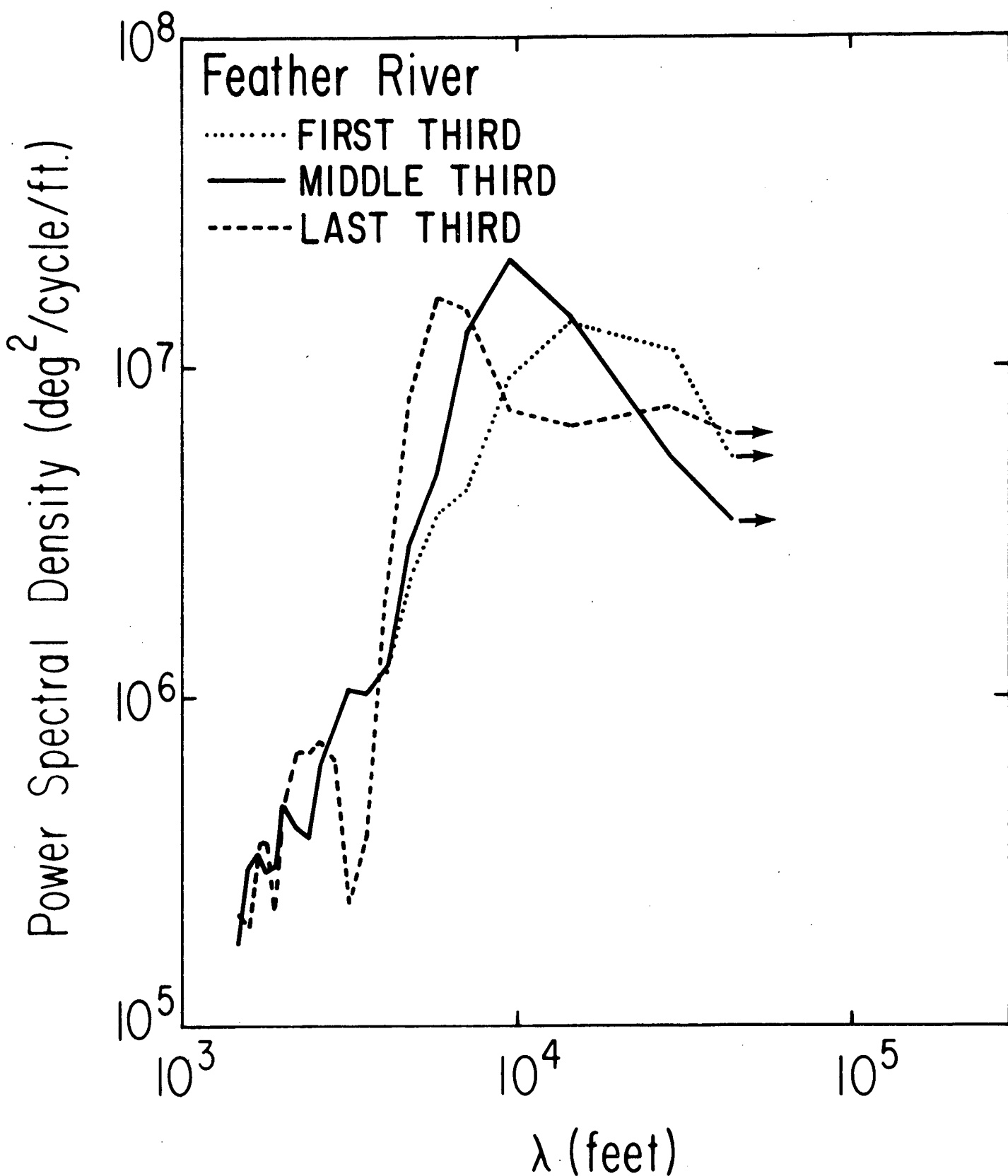


Figure 5.8. Power spectral density of three subreaches of Feather River.

### 5.1.3 Discharge Probability Density Function

Historical, daily streamflow data, in machine readable format, have been obtained from the Water Resources Division of the U.S. Department of the Interior. We have developed an algorithm to compute the probability density function of the discharge,  $Q$ , from these data. This function is the probability that the discharge lies within the interval  $\Delta Q$  at  $Q$ . The probability is determined by the fraction of the time that the discharge lies within this interval. We have also calculated the cumulative probability distribution function, which is the probability that the discharge is less than or equal to some value  $Q$ .

These functions computed from the daily discharge data for the Feather River near Oroville are shown in Figure 5.9 for the periods 1901-1933 and 1934-1967. As can be seen there is little difference in the probability density functions for these two periods which are prior to regulation of the flow by the Oroville Dam. Starting at the end of 1967 the discharge has been regulated at  $\sim 400$  cu. ft./sec., as is evident in the probability density function for the period 1901-1968 shown in Figure 5.10. Since this controlled discharge is outside the range of the previous discharge spectrum, we will investigate whether significant changes in the meander pattern occur.

## 5.2 FUTURE PROPOSED WORK

Having developed the procedures for generating the meander power spectra and the discharge probability density functions for rivers, we are now in a position to begin studying whether a correlation can be established between these two functions. Thus we have selected for

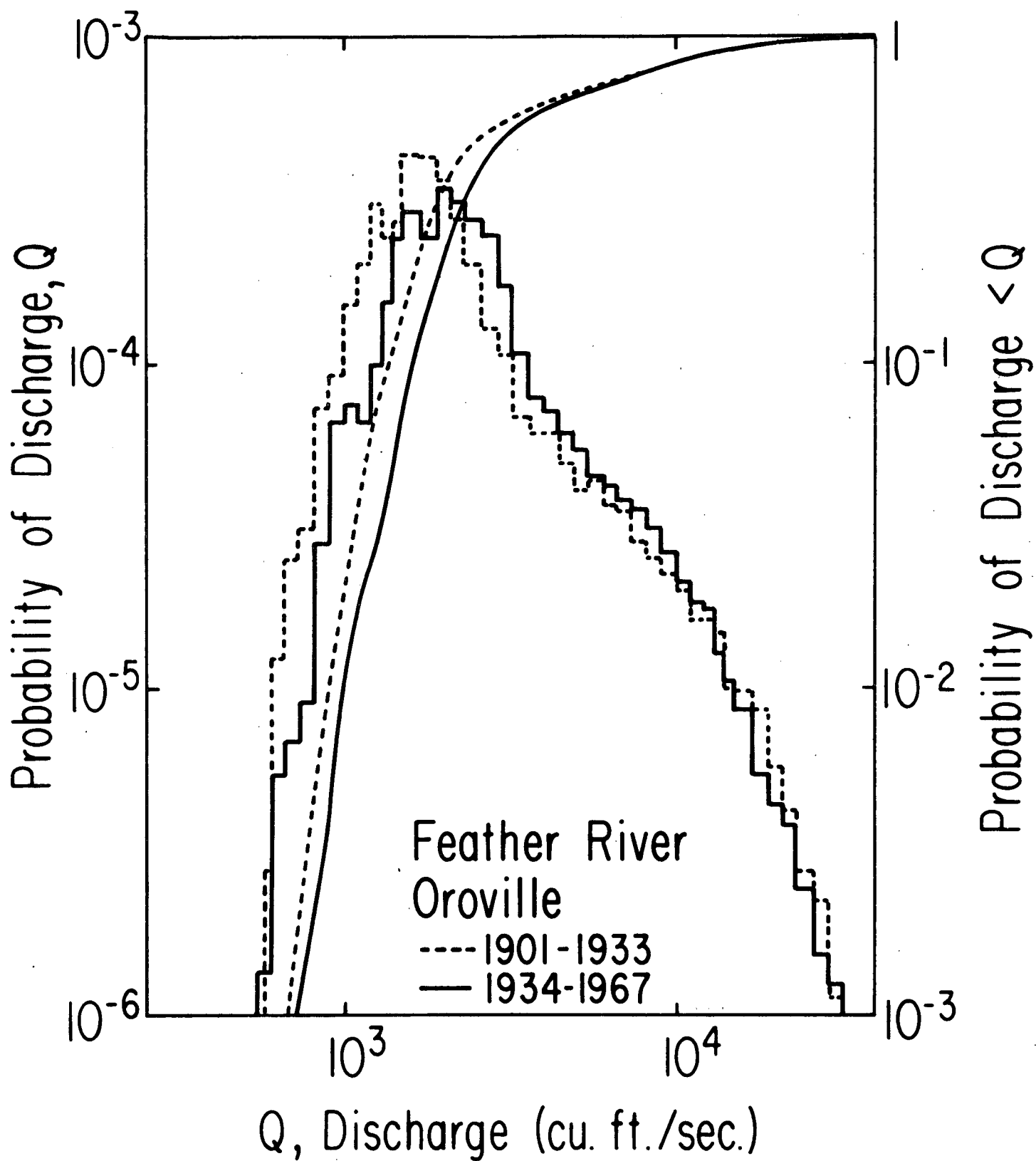


Figure 5.9. Discharge probability density functions and cumulative probability distribution functions for Feather River near Oroville for periods 1901-1933 and 1934-1967.

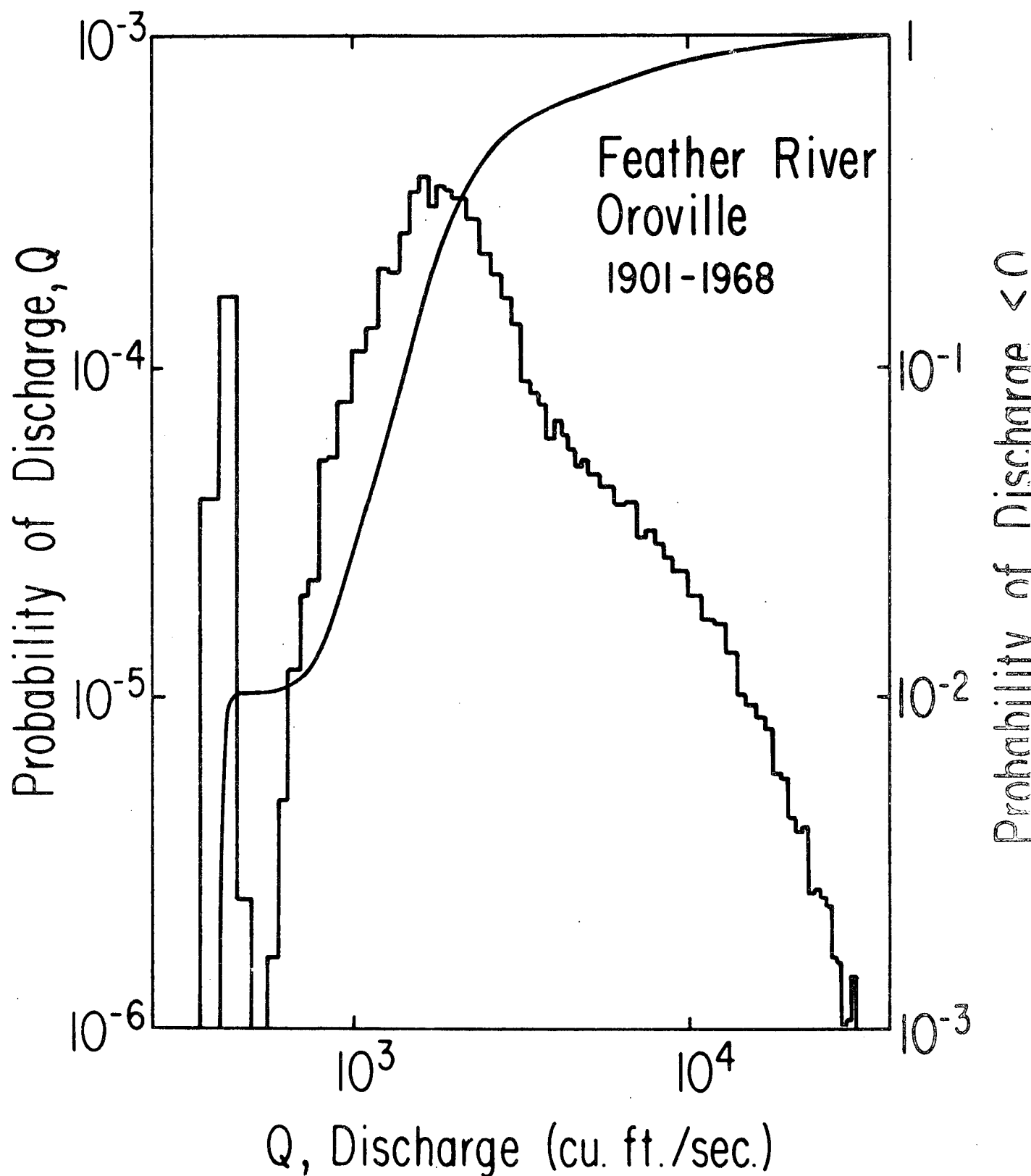


Figure 5.10. Discharge probability density function and cumulative probability distribution function for Feather River near Oroville for 1901-1968. Note separate peak in discharge at  $\sim 400$  cu. ft./sec. resulting from Oroville Dam control in 1968.

study several dozen river reaches, based primarily on uniformity of geology and availability of infrared photographic coverage or radar imagery and historical hydrologic data.

We have obtained the hydrologic data on the first 30 river reaches from the Water Resources Division of the U.S. Department of the Interior. We also have obtained infrared aerial photographs from the Forest Service and the Agricultural Stabilization and Conservation Service of the U.S. Department of Agriculture, and the Department of Water Resources of the California State Resources Agency. In addition, radar imagery has been obtained from the Earth Resources Research Data Facility at NASA Manned Spacecraft Center.

We are currently engaged in processing the data for these reaches in order to demonstrate quantitatively both the potential uses and limitations of our correlation study.

## CHAPTER 6

### ASSESSMENT OF THE IMPACT OF THE CALIFORNIA WATER PROJECT ON THE WEST SIDE OF THE SAN JOAQUIN VALLEY

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#### 6.1 INTRODUCTION

The research focus of the Geography Remote Sensing Unit at the University of California, Santa Barbara is an investigation of remote sensing applications that contribute to an understanding of the impact of the California State Water Project on the West Side of the San Joaquin Valley. Specifically, studies are being conducted of various regional scale parameters that can be used to characterize the nature of the area transformation that is taking place. Information is currently being extracted from Mission 164 remote sensing imagery for: land use, general and urban-oriented; vegetation, general and problem-oriented (boron and salinity affected areas); irrigation systems; and, identification of crops.

The photographic coverage of the area from Mission 164 (April, 1971) is complete with the exception of the 1:60,000 scale photography. The

lack of sufficient side-lap on this photography prevented complete coverage of portions of the area at the 1/60,000 scale, but this does not seriously impair the research effort. The quality of the photography in terms of resolution and sharpness is quite good for our purposes, although there were some exposure problems with the film (particularly with the color infrared). Camera exposures were pre-set causing those portions of the study area which are desert and highly reflective to be over-exposed. Despite these difficulties, the data appear to be compatible with present information requirements.

The present status of investigation is at the photo interpretation and field-checking level. The West Side of the San Joaquin Valley is a large area, and the studies being conducted are regional in scope. Considerable time is therefore required simply to convert the remote sensing data into information suitable for analysis and evaluation. In the case of land use mapping, sufficient information has been generated to indicate that good quality maps with general categories can be produced. Furthermore, the photography is of such quality that an expansion of the initial general land use categories, so as to include more detailed categories, is anticipated as a future part of the research effort. It would be premature at this stage to attempt to make similar comments for the other studies. It can be stated, however, that as the present phases of our study are completed, other phases will be initiated that will encompass more of the regional parameters necessary to understand the transformation



process that is occurring on the West Side. The following sections are provided to indicate the nature of specific phases of our study and the progress which has been made in conducting the study.

## 6.2 LAND USE

In an area undergoing a process of regional transformation, a significant indicator of the nature and degree of change is general land use. The major objectives of land use investigations on the West Side are: 1) the compilation of sequential land use maps to determine gross land use changes; 2) detailed examination of particular land use categories to detect specific patterns of development which are emerging; and, 3) the interface of West Side land use data with classifications generated in other areas in order to develop a workable system for automated mapping.

The approach employed in this study to achieve the above objectives is the construction and analysis of a series of land use maps from air photo mosaics and NASA-supplied imagery. General land use categories are being mapped to simplify identification, reduce interpretation errors, and provide a format amenable to slight modification to make it compatible with other land use classification systems being tested. The categories include transportation networks, settlements, oil extraction, cropland, grazing, and nonproductive land. Maps are being compiled for the dates of 1956-57, 1967, and 1971, based in part of the availability of photography taken during those periods. The 1956-57 period represents a relatively stable period of West Side land use and, therefore, serves as a good base from which to start

monitoring change. The 1967 period occurs just prior to receipt of California Aqueduct water and provides a good cut-off date for determining "normal" change patterns. The 1971 date is three years after receipt of new water and permits an analysis of aqueduct-induced changes in land use patterns.

Analysis of the ten-year period between 1956-57 and 1967 disclosed certain characteristics of West Side land use. At the start of this period the dominant land uses in terms of areal extent and economic importance were oil extraction and grazing. With respect to changes, the most significant patterns observed were an increase in the areal extent and relative intensity of oil extraction and agriculture. Oil extraction areas expanded their spatial boundaries, although these were primarily extensions of established sites rather than development of new ones. It was also noted that the intensity of oil activities increased as evidenced by higher densities of road networks and well spacing. Agricultural land increased slightly, but this was a process of filling in existing gaps in established areas rather than the development of new agricultural areas. These gaps were areas formerly classified as grazing or unproductive lands.

Preliminary examination of 1971 Mission 1964 imagery has revealed at least four major sectors of change in West Side land use since receipt of aqueduct water: oil extraction, waterways, Interstate Highway 5, and agriculture. Oil areas have continued to expand and intensify, although, as in the previous ten-year period, expansion was primarily confined to an extension into areas adjacent to existing

oil fields. By 1971, the California Aqueduct had been completed and water was being pumped southwards. Some lateral canals had been built and water was being delivered to farmers who had contracted for it. The course of Interstate 5 had been completely laid out and the roadbed cleared, although the entire length through the West Side had not been concreted. Some sections were open to traffic and were being used. Figure 6.1 shows a section of the California Aqueduct and Interstate highway near Kettleman City. The greatest areal change, however, was noted in agricultural land use. The total amount of cultivated land appears to have almost doubled with the addition of a new water supply. The majority of new acreage lies west of the canal and north of state highway 58, although there is also a filling in of previously uncultivated land between the canal and the older, established agricultural areas to the east. Figure 6.2 shows one of the largest of the new agricultural areas, a major component of which is 15,000 acres belonging to Belridge Farms (a subsidiary of Belridge Oil Company). Figure 6.3 is an aerial view of the Pleasant Valley portion of the West Side with a diversity of land uses.

Completion of the 1971 land use map will permit a more comprehensive analysis of general changes in the West Side. It will then be possible to select appropriate areas for a more intensive examination of land use. The results from these investigations can then be used to establish compatibility levels with other land use classification

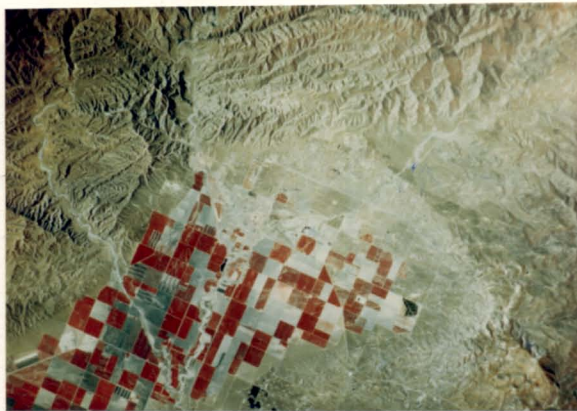


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Figure 6.1. The California Aqueduct and Interstate Highway 5 are inducing startling changes in the West Side landscape. Sections of the canal (dark blue) and highway (light tone above and paralleling the canal) are shown here near Kettleman City.



Figure 6.2. The agricultural area, displayed on this color infrared aerial photo, is Belridge Farms. The development has resulted primarily because of increased water availability because of construction of the California Aqueduct and represents 15,000 acres of new cultivated land.



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Figure 6.3. This aerial view is of the Pleasant Valley portion of the West Side. A myriad of land uses can be seen, including: urban (Coalinga), oil extraction, grazing, and agriculture.

schemes (e.g., the Riverside campus work) leading to the formulation of a more comprehensive automated mapping system.

### 6.3 CROP IDENTIFICATION

In most agricultural areas, it is very difficult to identify major crops on imagery from a single date. The difficulty arises from the fact that similar spectral responses are exhibited by a variety of crops when imaged at any particular time. However, crops, which display similar tonal signatures at one point in time, may not have the same appearance at other stages of a growing season. Plants undergo phenological changes as they grow and mature. These changes are reflected in a variable signature for a crop as it progresses through its growth cycle. A remote sensing survey of agricultural conditions must take these factors into consideration and incorporate some form of sequential monitoring.

The West Side poses certain indigenous problems for the development of crop identification techniques. As a direct result of the California State Water Project, a great deal of formerly unirrigated land has come under cultivation. The major portion of the new land is in close proximity to the California Aqueduct. The additional water permits a wide variety of crops to be grown, although local soil conditions must be considered. Excesses of salts and boron concentrations in the soil limit the crops which can be successfully grown. Presently, the majority of crops in the area are being cultivated on an experimental basis in order to determine those best-suited to environmental conditions and which are marketable. As a result,

crop patterns in specific fields are in a continuous state of flux, and no fixed crop rotation schemes have emerged.

Basically, the system of crop identification which is being developed incorporates two major elements of agricultural systems:

- 1) a monthly record of the sequence of crops growing in specific fields (crop rotation cycles on an individual field basis); and
- 2) a calendar depicting the general growth and harvesting pattern of the various crops grown in an area. This information indicates what crops are grown, when they are grown, and normal rotation cycles followed in fields. Using sequential imagery, it is then possible to identify crops on an elimination basis. Given imagery at a particular point in time, the first step is to determine whether a field is vegetated or bare soil. If a field is vegetated, the crop calendar is examined to find out what crops would be growing during this time frame. This narrows the range of choice as to what the crop in that field is. The final step is to check the history of the particular field under question in order to: 1) find out when the crop was first planted; and 2) determine the pattern of the prior rotation cycle in that field. The above procedures should permit, in theory, high accuracy identification of crops in most instances.

A major problem in applying this system of identification to the West Side is that everything is in an experimental state. There has been no stabilization of crops grown, nor of rotation cycles. A further complication is the lack of adequate sequential imagery of the area. In order to test the system, it is necessary to circumvent



the latter problem. This is being done by simulating sequential photography with adjusted monthly crop ground truth data. The data, which have been collected for over a year, were transformed from identifying the specific crop in a field to identifying whether the field was vegetated or bare soil. The assumption, based on considerable previous research, was that this is information which aerial photographs can provide almost 100% of the time with almost no error (particularly with color infrared).

Some preliminary tests were conducted with April, 1971, color infrared, 1/60,000 scale photography. The objective was to determine what problems might result from the simulated photographic data, and how these might be compensated for. Four people unfamiliar with the system were asked to identify the crops in approximately six hundred fields. The results were initially disappointing--only 60% of the fields vegetated in April were identified correctly. However, it soon became obvious that the sequential photography, simulated from ground truth, was causing some confusion. Further adjustment of the ground data is necessary to provide the interpreters with a more accurate simulation of what would appear on an air photo. Once these adjustments have been made and the crop calendar refined, testing will be resumed on a non-dry-run basis.

#### 6.4 IRRIGATION SYSTEMS

A marked characteristic of the new agriculture on the West Side is the almost complete absence of row flooding as a form of irrigation.



The high cost of leveling often steeply sloping land, subsidence of soil owing to hydrocompaction, the necessity to leach soils, the problem of hardpans forming in areas subjected to excessive amounts of standing water, and the relatively high cost of water (\$15 to \$30 per acre-foot) are all considerations that argue against the row flooding method.

Over 90% of the new acreage is presently being irrigated by some form of sprinkler system. The cost of such systems is high, varying from \$120 to \$1000 per acre, but they possess a number of advantages with respect to the West Side environment. The rate of water application can be controlled much better and spread more evenly than with row flooding. There is a minimal loss of water through runoff. Finally, land does not have to be leveled for the first planting of crops or for successive plantings (a costly operation in an area like this where subsidence is a problem).

It is important for the photo interpreter to be familiar with the more common types of sprinkler systems being used in this area and of the consequent effects on the aerial photographic appearance of fields in which such systems are present. Examples of some systems in use are:

- 1) Stationary and Side-Wheel Line Sprinklers. Both utilize sprinklers attached to a pipe which extends over the width of a field. With the stationary system, pipes are located from 10 to 50 feet apart. This allows complete coverage without having to move irrigation pipes. The side-wheel

system is composed of a single pipe forming an axle for several large wheels. Water pressure produces the power which moves the sprinkler slowly along the length of the field. Approximate cost of the side-wheel system is \$250 per acre. Stationary systems range in cost from \$400 to \$1000 per acre, depending on the distance between lines.

- 2) Trimatic. This system is similar to the Side Wheel except that, instead of an area being irrigated along the main pipe, a series of secondary sprinklers are dragged behind it. Approximate cost is \$400 per acre.
- 3) Hose Pull. This system consists of a single pipe with many hoses attached to it. It is portable and primarily used to irrigate trees. Approximate cost is \$500 to \$600 per acre.

In general, portable systems are least expensive and are used for irrigating field crops. Semi-portable systems are in a middle price range and are normally found in association with vegetable crops. Permanent systems are the most expensive and are used for tree or other very high value crops where a high return justifies the high investment.

Mission 164 photography was examined, and it was found that the irrigation systems could be identified on the imagery. Each sprinkler system produces a definite soil moisture pattern related to the manner in which the water is applied. Figures 6.4 through 6.6

illustrate soil moisture patterns, associated with different sprinkler systems, that are identifiable on aerial photography. The detectability of such systems on imagery through moisture patterns will help solve the problem of crop identification, since particular sprinkler systems are used with certain classes of crops.

#### 6.5 URBAN CHANGE DETECTION

The objective of this study is to develop methods for detecting and monitoring urban change with data from high altitude and satellite imagery in conjunction with minimal ground truth collection. In order to achieve this objective, the investigative focus is directed towards change occurring in urban communities on the West Side related to the California State Water Project and Interstate Highway 5. It is expected that the structure and function of existing urban sites will alter in a corresponding fashion to other sectors of the area, as part of the more general regional transformation process. Photography from Mission 164 (April, 1971) is being used to establish a base from which to monitor change. A literature search is also being conducted to determine relevant indicators of urban change for the region and to evaluate existing methodologies for detecting urban change.

The urban sites which were selected for close examination are considered to be representative of economic conditions which may produce change. Kettleman City, Huron, and Coalinga are communities where the impact of regional transformation may produce visible

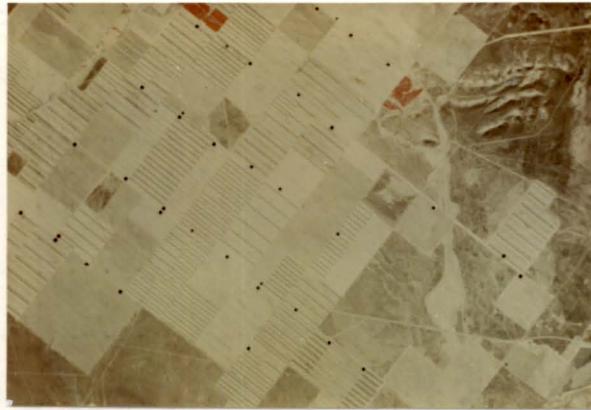


Figure 6.4. Stationary and Side Wheel line sprinkler irrigation systems on the Antelope Plain. The closely-spaced dark lines indicate the presence of stationary line sprinklers, while the more widely-spaced patterns represent mobile systems.



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Figure 6.5. Circular sprinkler irrigation systems on Belridge Farms near Lost Hills. The operation of the system dictates a circular field pattern, which is easily identifiable on aerial imagery.



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Figure 6.6. Line sprinklers and row-flooding east of Taft. The row-flooding technique can be seen just west of the California Aqueduct in the center of the photo. The characteristic pattern of the latter technique is a dark return fading into lighter tones across a field, caused by the release of water at one end of the field which then spreads across the field.

landscape expressions of change. Basic land use maps have been constructed from photography that was flown at a scale of 1/60,000. These show general land use of the areas in which the communities are situated. Subsequent maps (to be constructed from future imagery flown at this scale) will display changes in these basic categories, such as industrial parks, recreation development, or expansion of agriculture into areas previously unused. Maps of the urban areas are being constructed at a scale of 1/4500, since a larger scale is required to record and display the detail necessary to study an urban center. Indicators of change within the urban sites are expected to be morphological--e.g., commercial buildings, processing plants, areas of residential expansion, and improved transportation networks.

6.5.1 Kettleman City exemplifies the condition of a number of the small towns found on the West Side. It was developed as a minor service and residential area for local oil developments. The lack of continued growth of the oil industry in the area has caused the town to stabilize and then stagnate, there being no other local economic basis for development. However, the town is situated halfway between Los Angeles and San Francisco and is within 2 km. of Interstate 5. A local state highway, 41, links Kettleman City to Interstate 5, and it is anticipated that growth will occur along this corridor in the form of services such as motels, gas stations, and restaurant facilities. Transportation will serve as the stimulus

for anticipated changes in this town. Figure 6.7 shows an aerial view of the site, while Figure 6.8 is a map of the surrounding land use.

6.5.2 Huron represents an entirely different situation. The town developed as a supplier for local agricultural activities, furnishing machinery, packing sheds, processing plants, and other services. The expansion and intensification of agriculture, resulting from availability of California Aqueduct water and construction of Interstate 5, are expected to induce further growth in Huron related to its role as a supplier of agricultural services. Local observers contend that it may very well become the West Side's leading agricultural center. Monitoring will, therefore, concentrate on identifying new processing and handling facilities, new agriculturally oriented business establishments, and residential growth. One example of change already observed to be taking place is the construction of a new small housing tract on the eastern side of the town. Figure 6.9 is a color infrared photograph of Huron, and Figure 6.10 is a map illustrating the land use in the local area where the town is situated.

6.5.3 Coalinga is the second largest city on the West Side with a population of approximately 6,000. It first developed as a coaling station (from which the name Coalinga is derived), but the primary force in its growth was the oil industry. The city served as a supplier of tools and machinery for oil drilling, a residential site, a shopping center, and other general services that a large community can offer.





Figure 6.7 The Kettleman City area, with the California Aqueduct running across the upper third of the photo and Interstate 5 in the upper left. Note the intersection of Interstate 5 and State 41 at far left, a link that may stimulate the town's growth.



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Figure 6.9. An aerial view of Huron, an agricultural center located in the midst of an established cropping area.



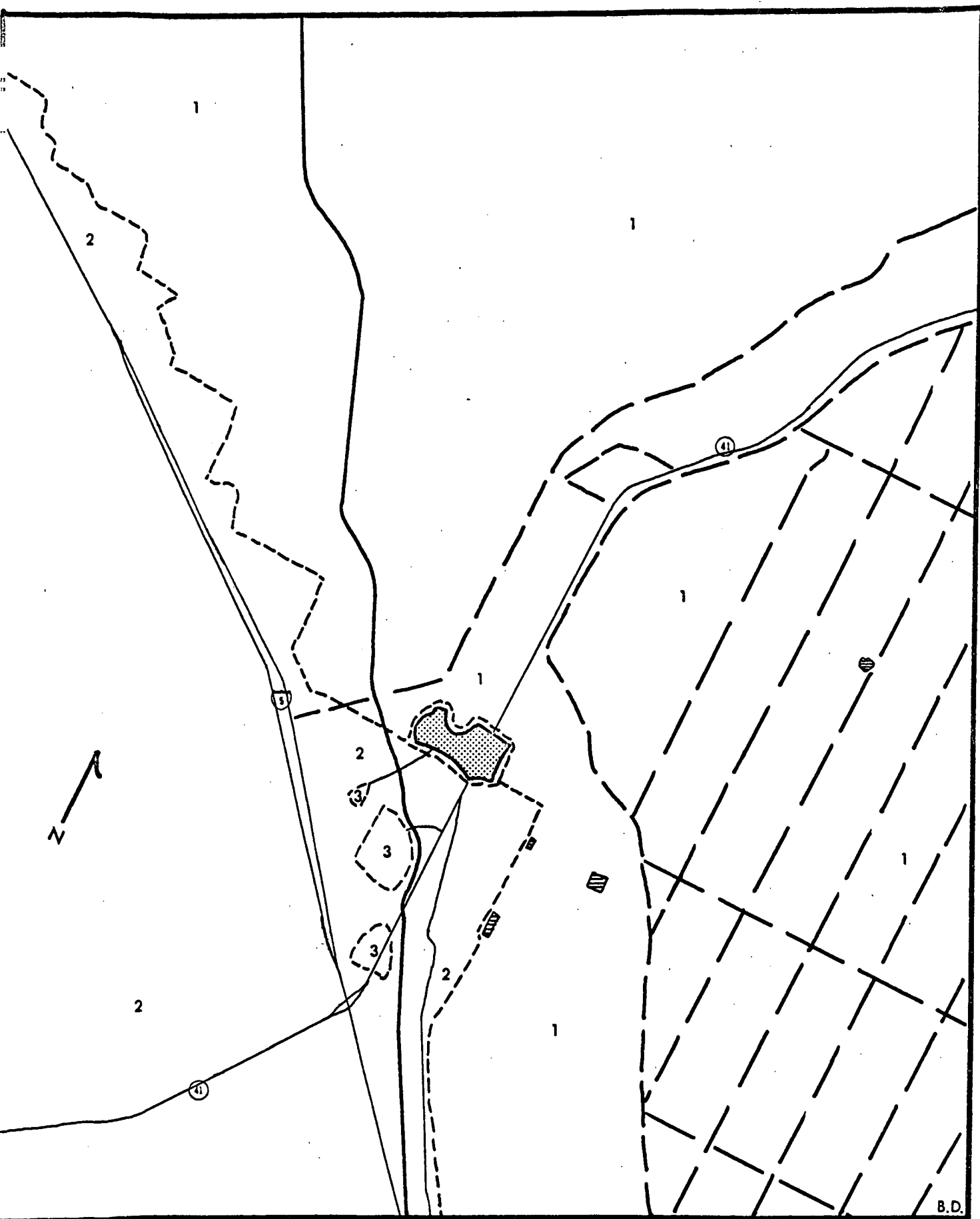




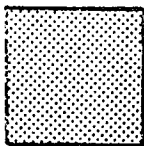


Figure 6.8. Land use map of Kettleman City area.

Land Use Key for Figures 6.8, 6.10, and 6.12.

	California Aqueduct
	Irrigation Canals
	Transportation
	Boundaries of Numbered Land Uses

- 1 Agriculture
- 2 Oil Extraction
- 3 Oil Storage and Facilities
- 4 Industrial
- 5 Grazing Land
- 6 Unproductive Land



Urban Area



Farm House Complex

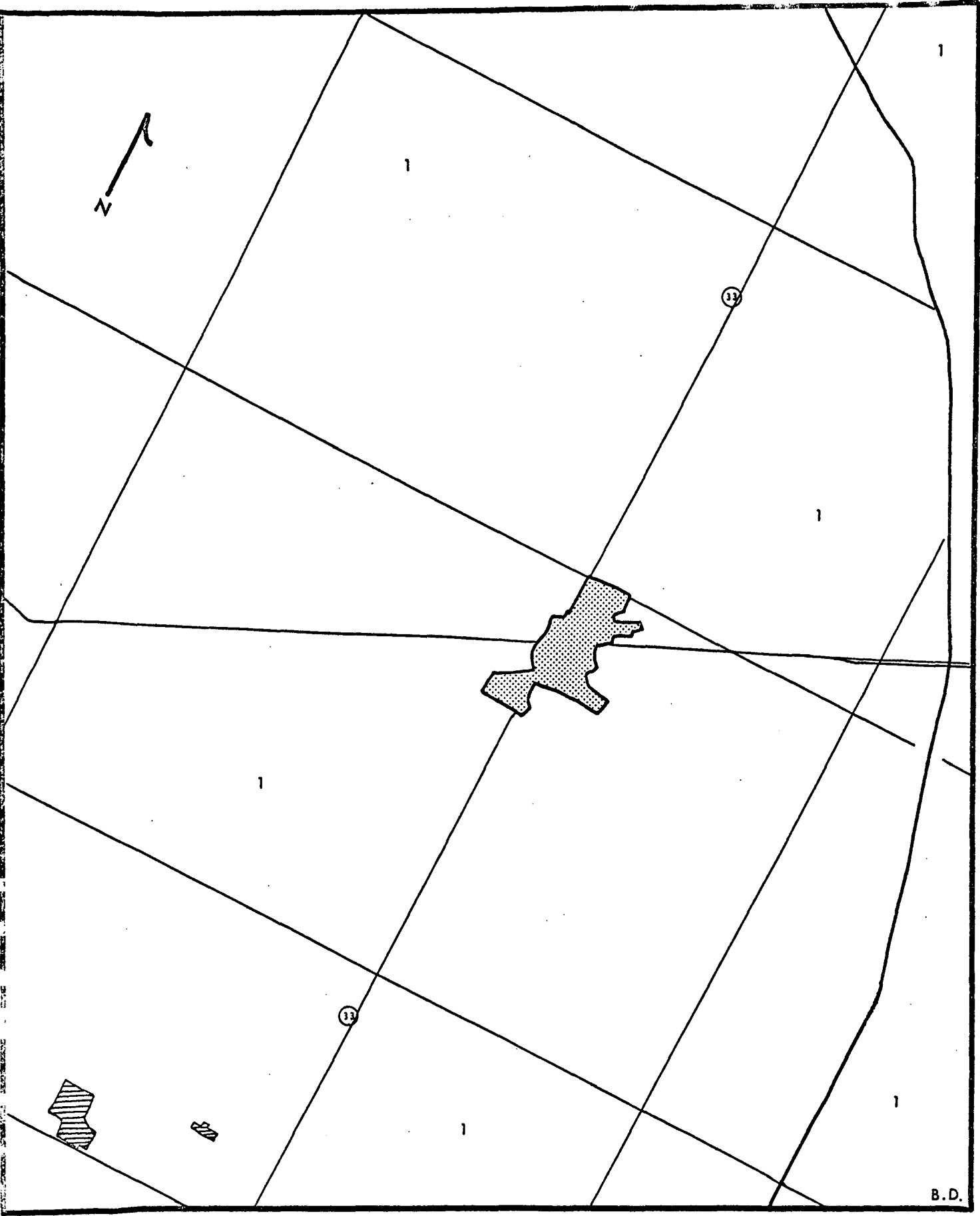


Figure 6.10. Land use map of Huron area.

Stabilization and automation of the oil industry, a poor and diminishing local water supply, and a location which is only peripheral to major areas of agriculture have served to impede further growth. Local officials expect that Aqueduct water and the new highway will provide Coalinga with avenues for diversifying and expanding its potential function as a regional center for the West Side. Aqueduct water will augment and vastly improve the quality of the existing supply, while the highway is expected to enhance the accessibility of the city to the region's residents and also to motorists traveling between Los Angeles and San Francisco. The principal shopping area is being reconstructed into a mall format, and there are plans to build agricultural processing facilities. Changes are starting to occur and will be closely monitored as our study continues. Figure 6.11 is an aerial perspective of Coalinga and its immediate surrounding environment, with Figure 6.12 showing the general land use of the area.

## 6.6 VEGETATION PATTERNS

The objective of this study is to produce a vegetation map of the perennial species for the West Side of the San Joaquin Valley, which will be comparable to previously published maps. It is hoped that the major boundary changes and some other minor patterns visible from the available imagery, can be explained with reference to human use of the land in the intervening time. Further communities delineated on the new vegetation map will be correlated with published soil maps

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Figure 6.11. Coalinga is one of the largest urban areas and is expected to develop into a regional center. This color infrared view shows the city in a setting of varied land use--agriculture, oil extraction, and grazing.

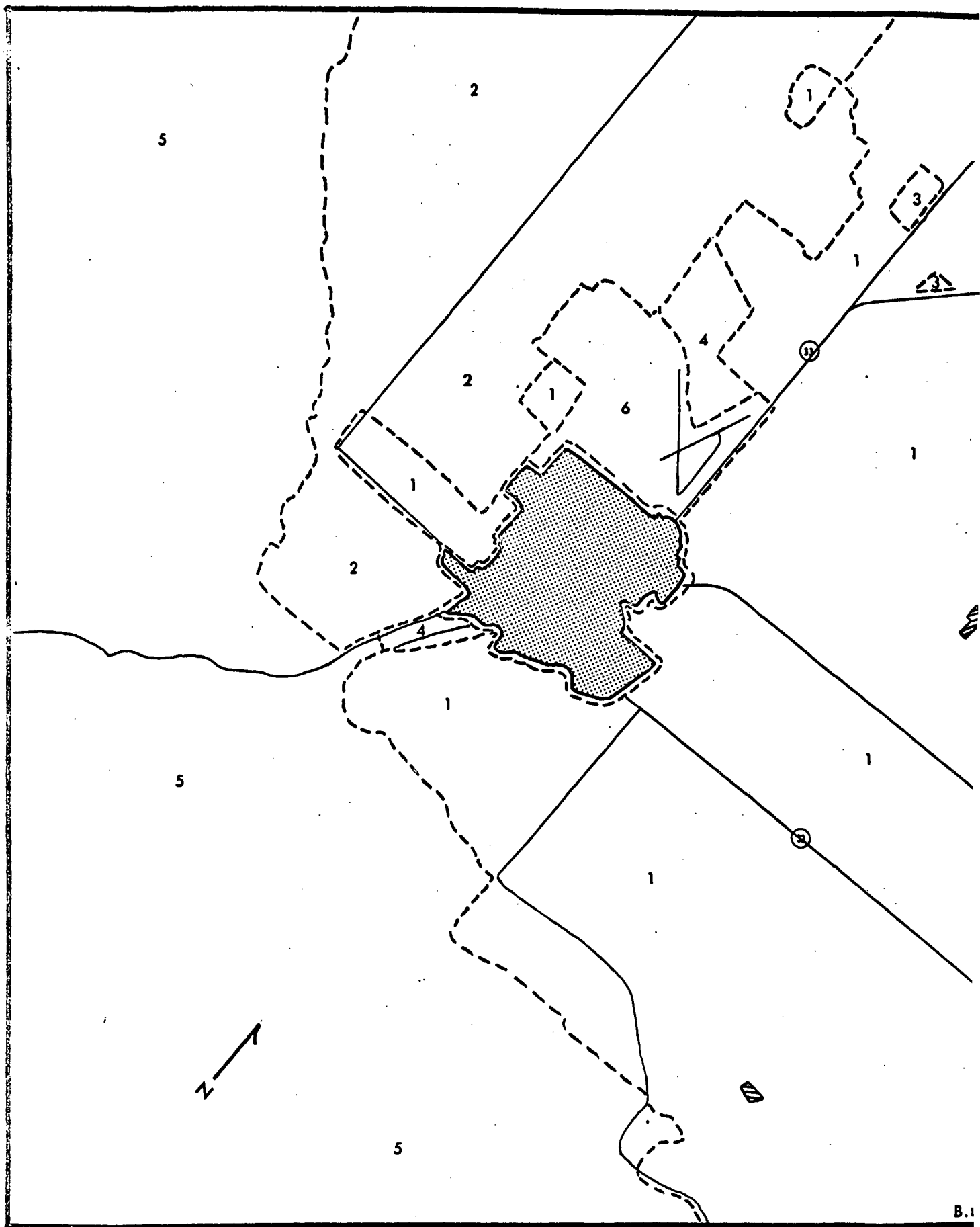


Figure 6.12. Land use map of Coalinga area.

and other soil data, specifically concerned with salt and boron concentrations. This will be done in the hope that some indicators among the native plant communities may be found to suggest areas of potential problems for agricultural development.

Previous research on the vegetation phase of West Side study included the gathering of published data on these vegetation communities and similar ones found elsewhere in the Southwest. Past vegetation maps were found to be of possible use in a comparative study. A reconstruction of pre-European vegetation was attempted by R. L. Piemeisel and F. R. Lawson, and a vegetation map illustrating the situation in 1937 was published in "Types of Vegetation in the San Joaquin Valley of California and Their Relation to the Beet Hopper." (U.S.D.A. Tech. Bull. No. 557, 1937). Preparations were made for remapping the West Side area using the same classification of communities. Necessary sampling methods were developed and some ground truth was collected in preparation for the construction of the new vegetation map when the imagery became available. In this preliminary work it was concluded that, since the annual vegetation consisted almost completely of introduced grasses and forbes, which showed little regional pattern, the later study would concentrate on explaining the regional variation in perennial species.

With the imagery now available, efforts were focused on the construction of the vegetation map. Patterns visible on the photography were isolated and related to variations in the shrub communities observed on the ground in subsequent field investigations.

The anticipation was the communities mapped by Piemeisel and Lawson could be distinguished on the imagery, in order that the proposed vegetation map depicting the present situation would be strictly comparable to the map published previously and illustrating past conditions. Some difficulty was encountered because the earlier work gave only non-quantitative, and often imprecise, descriptions of the communities. The present study will attempt a more exact characterization of the various communities. The simplicity of most of the mapped perennial associations enabled them to be delineated and mapped satisfactorily. All the associations described and mapped by earlier workers were mapped, although certain of the categories were found capable of further refinement to show patterns of internal variation observed both on the ground and from the imagery. The mapped communities are listed below with a brief description, and an indication of the degree of accuracy with which the boundaries would be differentiated on the photographs.

- 1) Winter Annuals--a community of annual plants, largely introduced grasses, distinguished from the other types by the absence of a shrub component. (fair)
- 2) Desert Saltbush--a shrub community dominated by a single saltbush species, Atriplex polycarpa. (good)
- 3) Spiny Saltbush--a shrub community similar in structure to the preceding type, but dominated by another saltbush species, A. spinifera. (fair to good)



4) Lowland Types--a community of several shrubs commonly recognized as salt tolerant. (good)

i. Seep weed--a community containing several salt tolerant types, but where seep weed (Suaeda) is the most abundant species. (good)

ii. Mesquite--a community similar to the above but where mesquite (Prosopis) is present and is conspicuous because of its tree-like proportions. (excellent)

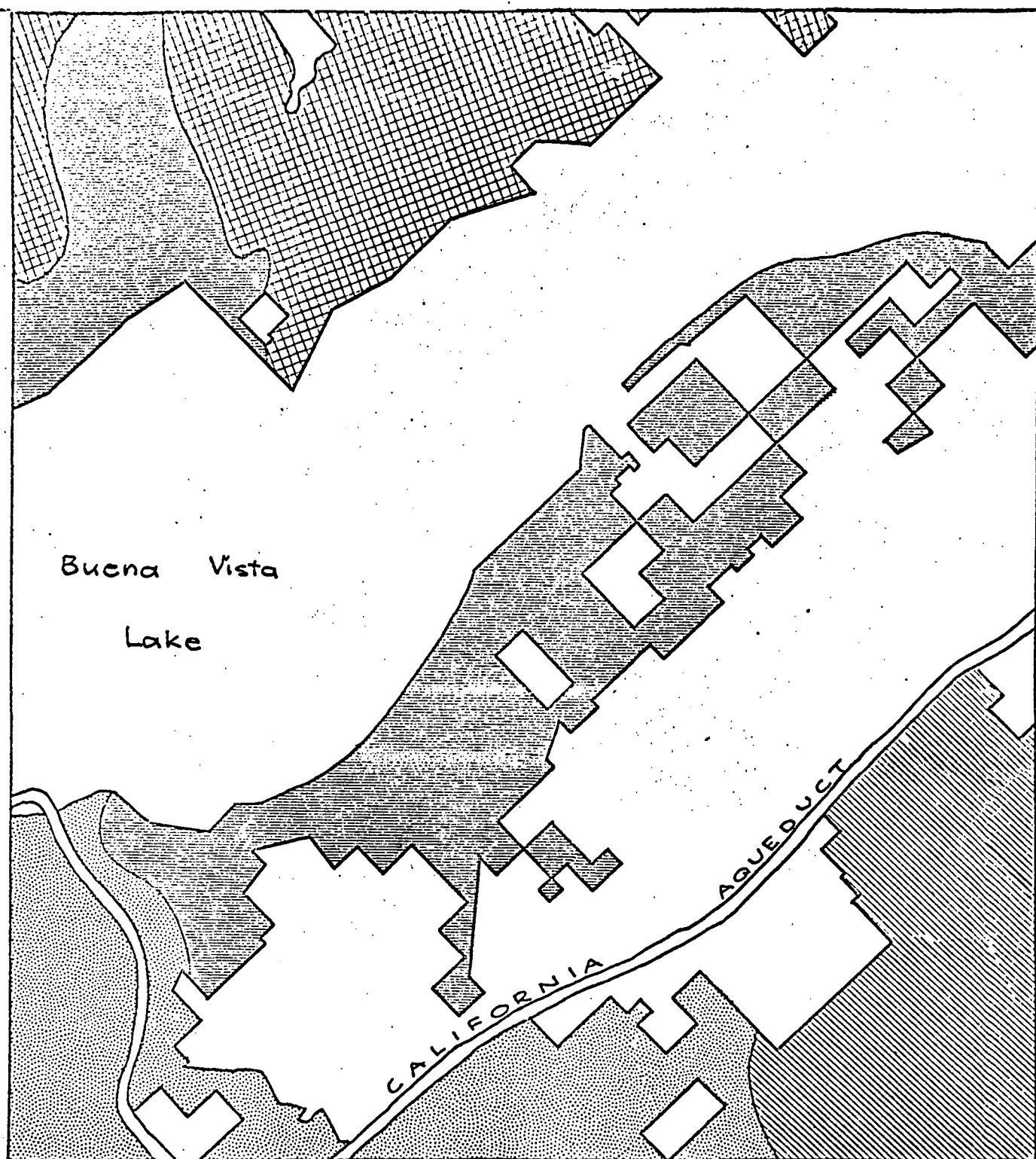
iii. Samphire--a community of small areal extent, and found in the most low lying areas. It is dominated by a Salicornia species. (poor)

In drawing boundaries we found the color infrared imagery to be the most useful, although the color photographs were occasionally helpful to clarify difficult interpretation areas. Photography at the scale 1/60,000 yielded more detail, but the coverage at this scale was not complete and the 1/120,000 scale imagery was used to do most of the mapping. The latter scale showed virtually the same gross patterns as were visible at the larger scale.

The vegetation map is essentially complete and an example, Figure 6.13, has been reproduced from the rough form as an illustration. It is expected that the final map will be at the scale of 1/250,000. Figures 6.14 through 6.19 are ground photos of the communities being mapped.

The new vegetation map illustrating the present situation on the West Side of the San Joaquin Valley shows some differences from that mapped in 1937 and from the reconstruction thought to depict pre-European patterns. Some differences may be the result of errors in mapping, but differential regional retreat of community boundaries requires other explanation. Human modifications by grazing, burning, clearing for agriculture, and attraction of natural drainage patterns appear to have been important. The true nature and relative importance of each of these factors are yet to be determined. Answers will be sought by obtaining information for sample areas singled out as being typical of much larger areas. Several large holdings have been owned and used by families over a long period of time, and it is thought that information on past human utilization may be available for some time into the past. Furthermore, precise information about the nature of the vegetation at known points can be obtained from old photographs. One important source of such photographs is believed to be a collection used in a study by W. H. Heisey conducted in the 1920's for the Carnegie Institution through Stanford University. It is expected that the sites of the photographs can be relocated, and the nature of the change in the structure and species composition at such sites can be investigated to produce further documentation of changes in community boundaries.

Further investigations leading from the construction of the vegetation map will be concerned with the characteristics of the soils on which each



# PLANT ASSOCIATIONS



MESQUITE



DESERT SALTBUSH



SEEP WEED



WINTER ANNUALS



CULTIVATED LAND

Figure 6.13. Sample vegetation map of Buena Vista Lake area.



Figure 6.14. Winter annuals. This is a community with almost a complete cover of annual grasses, but without a shrub layer.



NOT REPRODUCIBLE

Figure 6.15. Desert Saltbush. This community has typically a complete ground cover of annual grasses and a shrub layer up to three feet high, dominated by Desert Saltbush (Atriplex polycarpa). The association is commonly found on the higher, better-drained sites on hills and alluvial fans.



Figure 6.16. Spiny Saltbush. The ground cover of grasses in this community is often less than 100% and the shrub layer is lower than in the Desert Saltbush community. A saltbush species, A. spinifera, is dominant in this plant association, which most frequently occurs on the lower valley sides, and, occasionally, on the basin lands of the valley bottom.

NOT REPRODUCIBLE



Figure 6.17. Seep weed. This is the most open community with a very poorly developed ground layer of grasses. The several shrubs in this association tend to be low and widely spaced. Much bare ground is characteristic of the type.





Figure 6.18. Mesquite. This community is similar to the seep weed type in structure and dominant species, except for the presence of mesquite trees which give the formation a quite different aspect. Only where the Kern River spreads over the valley bottom is this community well developed.



NOT REPRODUCIBLE

Figure 6.19. Samphire. Dense stands of Samphire (Salicornia) occur in small areas of internal drainage. In such sites there is usually clear evidence of salt concentration. Although Samphire is easily distinguished on the ground by its bright green color, it is difficult to identify on the imagery available.

type occurs. Correlations with data on the levels of concentration of important salts and boron will be attempted. It is expected that the various plant communities will show different tolerances to these important chemical components of the soil. Soil analysis data are available from studies conducted by researchers at Agricultural Experiment Stations in the San Joaquin Valley and at U.C. Davis. Analyses from some 400 points in non-cultivated lands can be relocated and, hence, their relationship to the mapped communities determined. The patterns of perennial communities may prove to be of use as an indicator of soil types and may be valuable to indicate regions which may present problems for future agricultural development.

#### 6.7 BORON PROBLEMS

Boron is an essential element in the growth cycle of all plants. The specific requirements of plants vary greatly from species to species; however, the minimum requirements are quite small, ranging down to 0.2 parts per million (p.p.m.). Some plants are so intolerant of boron that symptoms of toxicity may be produced at concentrations as low as 0.3 p.p.m. On the other hand, some cultivated plants have very high requirements and naturally occurring concentrations in soils rarely result in plant damage. This variability in the response of plants to boron concentrations indicates the need for a map on the West Side, where boron occurs in highly variable concentrations, of the distributional pattern of the phenomena. Agricultural planners need this type of information to determine what crops can be grown in

what locations, and what remedial measures may need to be taken to improve soil conditions.

Investigations of potentially toxic levels of boron in soils prior to cropping have been restricted to time-consuming laboratory analyses of soil samples taken at varying depths from point locations. Detection of patternings in the spatial distribution of boron hazards has not been attempted, for the most part, because of several factors: 1) the great expense of laboratory analyses; 2) the difficulty of interpreting and generalizing the complex relationships between plant responses and boron from field observations; and, 3) the unavailability of cheap and efficient techniques for acquiring needed data.

In view of the above considerations, the objectives of this particular investigation are threefold: 1) to study the relationship of boron, and the soil chemistry of boron compounds, to crops; 2) to map and analyze the spatial distribution of boron compounds for selected sites where field data are available; and, 3) to evaluate the capability of remote sensing imagery to provide data needed for the identification and analysis of the spatial patterning of boron compounds.

The initial major effort has been the collection, compilation, and display of soil analysis data. A review of the literature on boron toxicity in plants and the chemistry of boron in soils is also nearly completed. It was recognized at the onset of the study that these steps would have to be completed before any meaningful interpretation of photography could be made. The most significant finding



from the ground truth data was that the distribution of boron concentrations appears to be a highly localized phenomenon. Boron concentrations can change dramatically over extremely small areas. This may well indicate that there is no general regional patterning, but that the distribution is instead related to very discrete and specific environmental conditions.

Color, color infrared, and spectrally filtered black-and-white photographs as well as thermal infrared images were examined in a preliminary fashion for evaluation. In terms of correlation with the ground data collected, all of these types of imagery appear to be useful and patterns do show up to varying degrees at all scales. Color infrared photography offers the greatest promise, since boron causes significant damage to vegetation of a type that is best revealed by such photography. Larger scale imagery, perhaps 1/10,000, with good resolution would probably be even more useful because there is highly localized variation associated with boron concentrations. Late summer or early fall would be the optimum time for acquiring photography, since these are the time periods when boron concentrations in the leaves of plants are the greatest.

N72-20350

## Chapter 7

### ASSESSMENT OF THE IMPACT OF THE CALIFORNIA WATER PROJECT IN SOUTHERN CALIFORNIA

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#### 7.1 INTRODUCTION

Research progress at the University of California, Riverside, under the NASA "Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques", is reported herein for the period since May 1, 1971. The research efforts consist of investigations of remotely sensed data applications that contribute to an understanding of the southern California environment and its resources. These investigations are being conducted at various locations and using regional scale parameters, by a variety of researchers, and for a variety of related topical applications.

#### 7.2 RECENT DATA ACQUISITION AND FACILITIES

##### 7.2.1 NASA Mission 164

The successful continuation of several of the investigations reported herein was greatly enhanced by the completion of several recent aerial photographic overflights. The most significant of these was NASA Mission 164, a high altitude (RB-57F) aerial reconnaissance overflight providing almost complete coverage of the southern California regional study area at approximate scales of 1:60,000, 1:120,000, and 1:475,000. A summary

of all recently acquired photographic data is given later in Table 7.1.

NASA Mission 164 was conducted between March 31 and April 5, 1971. Most of the data from it were received by the Riverside investigators in late May, 1971. (Some data have not yet been received. This fact has been brought to the attention of NASA/MSC personnel with recent assurances that the data will be delivered in the near future.)

Although not all of the data from Mission 164 have been precisely indexed for location and areal coverage (the large scope of this task requires that indexing be accomplished as the data are used in various investigations), only a few areas have been found to be lacking coverage to date. For these areas, however, other remotely sensed data (i.e., photography) are available and the void areas are not considered extensive enough for documentation or re-flight requests.

An important image quality problem of Mission 164 color infrared photography concerns exposure. Exposures for the RC-8 and Zeiss cameras were pre-set for flight and provided proper film exposure for the more heavily vegetated and moist areas of central and northern California. In southern California, however, vegetation is more sparse, the terrain is more highly reflective (particularly over desert areas), and there is a higher angle of incident solar energy. Camera exposures do not appear to have been adequately adjusted for these factors and, as a result, the color infrared photography is generally over-exposed by approximately one-half f stop. The combined effects of over-exposure and apparently low infrared sensitivity of the color infrared film make much of the data of marginal utility for the analysis of vegetation and other environmental components in the arid, desert regions. Between the 1:120,000

scale (RC-8) and 1:60,000 scale (Zeiss) color infrared photography, the latter is superior in terms of resolution, color balance, and spectral sensitivity. As a result, it has already proved to be preferable for investigations employing Mission 164 data and in studies that can tolerate the less extensive areal coverage.

#### 7.2.2 Additional Remotely Sensed Data Acquired

Mission G06 (July 13, 1970) acquired, from local sources, color infrared photography for the city of Riverside at approximate scales of 1:12,000 and 1:24,000. Our group has used this photography for various urban analyses in the local area. Mission G07 (July 21, 1970) acquired, from local sources, color infrared photography of Santa Cruz Island at an approximate scale of 1:22,000, and portions of the coastline between Santa Barbara and PalosVerdes at an approximate scale of 1:24,000. This photography is available for various coastal studies. NASA Mission 157 (February 9, 1971) acquired color (1:50,000) and color infrared (1:100,000) photography of the Los Angeles earthquake area and also of extensive portions of the metropolitan Los Angeles basin. This photography is useful for various urban land use and urban area analyses, and for coastal studies where coverage exists. Mission G08 (April 7, 1971) acquired, from local sources, color infrared photography, at an approximate scale of 1:16,000, for portions of the San Bernardino Mountains devastated by forest fires in the Fall, 1970. This photography facilitated a detailed study of the forest fire as well as an update and addendum to a previous study of montane vegetation, sponsored jointly by NASA and the Geographic Applications Branch of USGS. The above photography that was acquired from local sources did not employ NASA support; a report of

our findings based on that photography is included here, however, because the data are being used, or are available, for various NASA-sponsored investigations of the southern California environment.

### 7.2.3 Use of Data and Facilities

Since 1966 investigators at the University of California, Riverside, have maintained facilities adequate for the viewing and analysis of various remotely sensed data to support an on-going research program in southern California. In addition, a sizable library of reference materials and data has been developed. These facilities have also been available and extensively used by students of the University enrolled in the various remote sensing curricula and in research projects.

Since the receipt of Mission 164 data, providing total aerial photographic coverage of the southern California metropolitan and agricultural regions, there has been a noticeable increase in the desire of persons and organizations outside the university research and teaching community to use photography from our file. We feel that our assistance to these persons and organizations, and their beneficial use of our data and facilities, is an important service of the university. Thus far such activity has not seriously interfered with our research program and objectives. Because of this growing interest, however, our time and facilities are increasingly utilized. We are presently considering alternative methods to cope with this situation (before it becomes a restrictive burden to the research program and its staff), while also maintaining our close cooperation with various data users.

## 7.3 SUMMARY OF CURRENT INVESTIGATIONS

Several investigations are in progress which deal with the

Table 7.1

## RECENT REMOTELY SENSED DATA ACQUISITIONS

University of California, Riverside  
Department of Geography

<u>Mission</u>	<u>Date</u>	<u>Film</u>	<u>Approximate Scale</u>	<u>Area</u>
G06	7/13/70	CIR	1:12,000	City of Riverside
G06	7/13/70	CIR	1:24,000	City of Riverside
G07	7/21/70	CIR	1:22,000	Santa Cruz Island
G07	7/21/70	CIR	1:24,000	Coastline areas, Santa Barbara to Palos Verdes
*157	2/9/71	Color	1:50,000	Los Angeles area
*157	2/9/71	CIR	1:100,000	Los Angeles area
*164	3/31-4/5/71	CIR	1:60,000	Southern California
*164	3/31-4/5/71	CIR	1:120,000	Southern California
*164	3/31-4/5/71	CIR	1:475,000	Southern California
*164	3/31-4/5/71	Color	1:120,000	Southern California
*164	3/31-4/5/71	Color	1:475,000	Southern California
*164	3/31-4/5/71	B/W	1:475,000	Southern California (multiband)
G08	4/7/71	CIR	1:16,000	San Bernardino Mountains

\*NASA Sponsored

applications of remote sensing data in the study of earth resources in southern California. Briefly, these investigations by researchers at the University of California, Riverside, are as follows: (1) inventory of rural land use and monitoring land use change related to Lake Perris in the Perris Valley, California; (2) development of models and methodologies for utilizing remotely sensed data for regional information systems; (3) utilization of synoptic photography to develop techniques for urban and regional planners to establish guidelines in rural-urban transition situations, and to monitor and evaluate the impact of transportation developments on land use change through a case study in the Walnut Valley, California, area; (4) an update of a previous NASA study to map montane vegetation in Southern California from color infrared photography using recently acquired high altitude data; (5) development of methodologies and production of gross land use maps, using computer graphics, for the NASA funded USGS Atlas of Urban and Regional Change, with a land use study of the Riverside-San Bernardino region; and (6) an examination into the use of remote sensing as a technique for assessing environmental quality as affected by the impact of urbanization in Southern California.

Several of the above NASA-California grant studies are related to, or are integrated with, other studies being conducted by researchers at the University of California, Riverside. In such cases, proper credits of joint, or combined, activities and support are given in the following discussion of specific activities.

#### 7.3.1 Rural Land Use Inventory and Change: Perris Valley

A primary investigation of the Riverside researchers during the past 18 months has been that of preparing a data base for analyzing the impact

of the California State Water Project, and its terminal reservoir, Lake Perris, on the land use and development of the surrounding Perris Valley. Researchers are investigating the effects and implications of water transfer on domestic, industrial, agricultural, and recreational land uses and regional development, as observed and recorded by high altitude aircraft and spacecraft remote sensing devices. These studies initially followed a rather intensive analysis of a small study area, and considered several social and economic factors which can influence regional land use and development. Results of these studies have been reported previously and are only summarized in the following discussion. Recent approaches have been designed to expand the area of study, and subsequently to generalize and reduce the detail and resolution of data recorded and analyzed. Thus, an approach to a local environment is evolving into one of a regional environment, yielding a technique that is more applicable to the areal analysis of spacecraft and simulated spacecraft type data.

#### A Summary of On-going Studies

Previously reported studies included (1) a land use survey of a sample study area using both ground observations and the interpretation of high altitude color infrared metric photography; (2) a survey of residential attitudes towards the development of Lake Perris and the Perris Valley, and activities by local developers and planners in the area; and (3) a preliminary study of methods for estimating potential population, development and expansion, and/or land value increases in the Perris Valley using conductive sheet analog models.

The sample study area for land use survey was Riverside County



census tract 426. The tract was 29.81 square miles, or 19,081 acres, in area and lies adjacent to the future Lake Perris. Land in agriculture was tabulated and analyzed. It was found that approximately 39.4% of the total census tract area was irrigated agriculture, primarily vegetable and forage crops, and approximately 50.5% of the area was dry farmed, primarily barley and wheat. Another 11.1% of the total area was classified as "presently unused".

The study area was subsequently enlarged to 175 square miles and surveyed using both ground observations and aerial photo analysis. The selection of the study area boundaries was dictated by high altitude aircraft photographic coverage obtained on NASA Mission 128B (approximate scale 1:100,000). Suitable base maps for field surveys were prepared and the area was sample surveyed at the time of NASA Mission 164. Recorded for each field in the sample survey were crop-type and irrigated/dry farmed data. All data were recorded on a master map of the study area. The delivery of Mission 164 photography delayed any further analysis of Perris Valley land use until the beginning of the present reporting period, May 1, 1971.

The questionnaire survey conducted in the Spring of 1971, attempted to assess by limited sample how people in the rural areas of the Perris Valley felt about the California State Water Project and the development of Lake Perris. The area surveyed was the western half of census tract 426, which excludes any towns or urban-like developments. The principal sources of livelihood for those persons surveyed were farming (dry and irrigated), horse ranching, and poultry raising. These persons were also those most affected by land prices, property assessments and taxes

concomitant to the creation of Lake Perris.

As previously reported the local residents had never been contacted in any way regarding their attitudes toward the California Water Project and the survey results were most interesting. For the most part, the people supported the project; they felt population would grow because of Lake Perris and that industry would develop in the area. Their feelings were divided almost evenly on whether or not they favored the development of industry. However, most of them definitely felt that pollution of the environment would increase. Most of them said they would move in the event of a substantial increase in population and industrial development. To the question, "If you dry farm, would you change to irrigation if Lake Perris water rates were reasonable?", the response was split, 47% said yes, 21% no, and 30% gave no response.

The questionnaire was not perfect. This was partly due to the vagueness of some questions. But on the whole, despite the rather arbitrary sampling technique, the response was very good and informative. The people want the project and regional growth, yet many indicated they would move because of it. Perhaps this dichotomy can be explained because no one can really comprehend what the impact of Lake Perris will be on this area. While land owners may gain tremendously through the sale of their land at rapidly increasing land prices, they also may see that the continuance of agriculture in the area is in jeopardy.

The general attitudes toward development and change in the Perris Valley do not seem, by casual observations, to have shifted significantly in recent months. The Riverside County Planning Commission has recently initiated a general plan study for the Moreno Valley, which is that

portion of the Perris Valley study area north of the Romona Expressway and including the Lake Perris site. It is anticipated that Mission 164 data will be utilized in the study. It will be many months before its completion, however. In previous reports it was suggested that a similar, more expanded, survey of regional attitudes be conducted. This suggestion is still endorsed although it is felt that a present survey would be premature. Rather it is recommended that such a study be initiated several years hence, after the initial impact of Lake Perris has been felt in the region.

Similarly, the earlier applications of conductive sheet analog models for analyzing potential population, development and expansion, and/or land value increases in the Perris Valley proved to be both enlightening and useful in preliminary studies. Further efforts of this type are recommended in the future. It is believed that spacecraft type data will be very useful in such studies.

#### Research Undertaken Since May 1, 1971

Soon after the beginning of the present reporting period, May 1, 1971, Mission 164 high altitude photography was received. Because of the large quantity of data obtained during Mission 164, considerable time and effort were first required to evaluate and index the data. Upon completion of the data evaluation and indexing, it was possible to resume investigation of the Perris Valley Study Area.

As previously stated, the Perris Valley Study Area was enlarged at the time of the Mission 164 overflight to an area of approximately 175 square miles. This area, shown on Map 7.1, was based on similar data coverage by Mission 128B. Concurrent to the Mission 164 overflight a

ground survey was conducted to record agricultural land use in approximately 53% of the Perris Valley and vicinity. Acreage for each land use category surveyed on the ground was as follows: field and seed crops, including wheat, barley, oats, alfalfa, and sugar beets, approximately 38,000 acres; vegetable crops, including onions and carrots, approximately 800 acres; tree crops, primarily oranges and avocados, approximately 1,100 acres; and animal husbandry, including feed lots, poultry operators, horse breeding farms, and permanent pastures, approximately 3,000 acres. There were approximately 19,000 acres classified as fallow, plowed, and recently harvested; and 18,000 acres located mostly on the hillslopes and high saline areas along the San Jacinto River drainage were classified as undeveloped or abandoned. Urban and residential areas account for approximately 8,000 acres; March Air Force Base is about 2,000 acres; and the state-owned Lake Perris site and surrounding Mt. Russell and Bernasconi Hills comprise 22,500 acres. This represents a total of 112,500 acres, or about 175 square miles of ground survey.

Considerable time has been required to convert the interpretations from Mission 164 data and the ground survey data into information suitable for analysis and evaluation, and to expand the base maps to provide a study area in the Perris Valley amounting to about 175 square miles. USGS 7-1/2 minute topographic sheets were used in conjunction with the aerial photography to prepare the base maps. Mission 164 imagery of 1:60,000 scale generally proved more useful in determining field boundaries than 1:120,000 scale imagery. The next step was to interpret land use from the 1:60,000 and 1:120,000 photography and correlate the interpretations with available ground survey data.

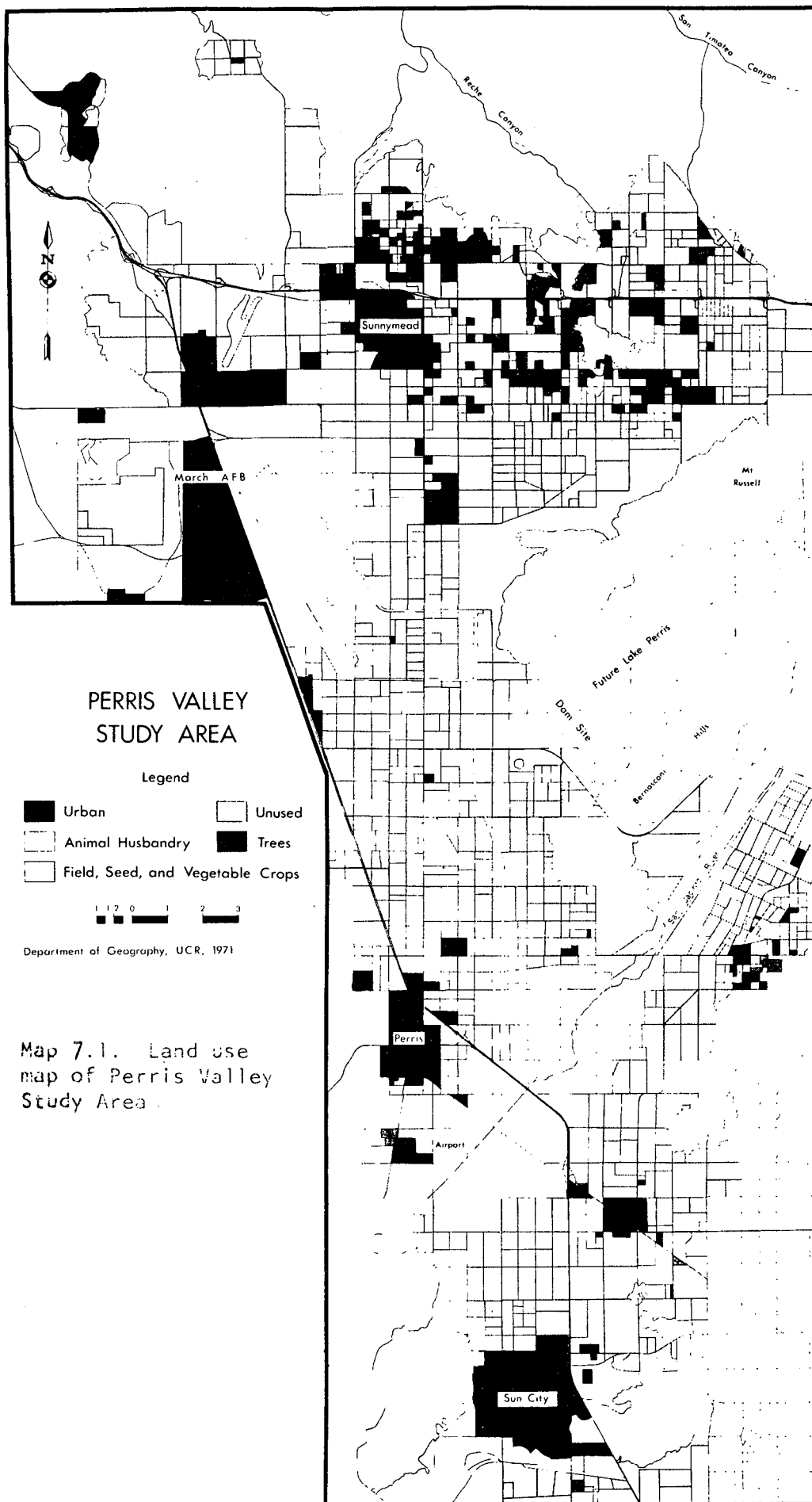
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One of the purposes of the investigation is to determine, from remotely sensed data, to what degree the California Water Project will affect the extent of irrigation in the Perris Valley. This, however, has not been possible to determine at either 1:60,000 or 1:120,000 scales (although irrigation is generally assumed for all vegetable, fruit, and tree crops in this area). Ground resolution on either scale of photography is generally not fine enough to determine row crops (except trees) and it therefore has become necessary to classify vegetable crops with field and seed crops when mapping the photointerpreted data. At the scale of 1:120,000 it often has been impossible to determine the existence of abandoned or recently planted orchards, partly due to resolution but primarily due to film color balance -- an intense greenish cast of the film subdues all but the most intense shades of red. This also prohibits discrimination of recently seeded fields from bare ground, although this distinction can generally be made on the 1:60,000 scale imagery. The 1:60,000 scale imagery has thus far proven to be the most useful data acquired during Mission 164 for the present needs and purposes of this study. Lack of sidelap, however, has sometimes caused increases in interpretation errors where it has been necessary to use the smaller scale, 1:120,000 imagery. In order to circumvent this problem, it was necessary to further generalize the land use categories as previously employed in interpretation and ground survey.

Generalization of land use categories usually implies a loss of certain information. There are, however, several advantages to generalizations which still retain useful categorization. Because of the low resolutions specified for the high altitude aerial photographs for pre-ERTS

simulation studies, and the ERTS data itself, it will be impossible to discriminate the detailed information implied in our previous data classifications. A data base to be used for such future data evaluations should consist of categories which are applicable and meaningful to the interpretation of low resolution data. Also, the study and mapping of large regions, as is discussed later in this report, necessitate data generalizations when such areas are mapped and analyzed at small scales. Therefore, a new set of land use classifications for the Perris Valley Study Area is introduced on Map 7.1. These are: (1) Urban (including all urban and "urban like" areas, and areas owned by local governments); (2) Tree Crops (all types); (3) Animal Husbandry (including poultry, feed lot and horse breeding activities, and permanent pastures) (4) Field, Seed, and Vegetable Crops (i.e., Generally all agricultural land uses not classified in (2) or (3)) and (5) "Unused" Land (including mountain and hill areas, areas of high soil salinity, etc.). Within these five categories, approximately 487 square miles have been interpreted and mapped.

Map 7.1 shows approximately 688 square miles of the Perris Valley Study Area, of which approximately 487 square miles have been mapped for a 1971 land use data base from both Mission 164 photographic interpretations and concurrent ground survey data. General location annotations are given on the map, including Urban areas, March Air Force Base, and the state-owned land surrounding future Lake Perris (unmapped in above figures). The approximate areas for each category are as follows: Urban, 58 square miles; Tree Crops, 10 square miles; Animal Husbandry, 10 square miles; Field, Seed and Vegetable Crops, 239 square miles; and "Unused"



Land, 170 square miles.

The Perris Valley land use data base is still incomplete. Progress is underway to expand the boundaries further and to integrate the Perris Valley study area with the Riverside-San Bernardino and vicinity regional study (Section 7.3.5). This expansion and integration will allow the data base to be computerized for rapid display, analysis, and update. It will also adopt the regional land use classification scheme which is extremely flexible in that it provides for both detailed and generalized data depending on the fidelity of the source materials.

#### Image Enhancement Experiments

Several preliminary experiments were conducted to evaluate the potential application of color image enhancement techniques to high altitude multiband photography of the Perris Valley. The multiband photography (Mission 164) is similar to that expected in the ERTS simulation program, and of the same spectral characteristics as will be acquired by ERTS. Optical enhancements were made on the FRSL Optical Combiner; electronic enhancements were made on the I<sup>2</sup>S Multiband Camera Film Viewer (MCFV) prior to its delivery to NASA/MSC. A preliminary evaluation of several of the processed images is given in the following paragraphs.

Image enhancement of two types was conducted of the 70 mm multiband photography of the Perris Valley area. A set of prints was made from the optical enhancement of the multiband black-and-white imagery (70 mm). The multiband photographs used were: green (Pan with a 58 filter), red (Pan with a 25 filter), and the near infrared (black-and-white IR with an 89B filter). The prints were compared with the multiband imagery to



determine any improvement in the capability to detect and identify major land use types. Of the enhancement combinations, three prints appear to have some utility. In general, there is one principle advantage provided by the optical enhancements: the addition of color to the imagery. This aids in making more precise distinctions between grey tones. The three prints provide three separate color combinations which allow accurate detection of areas which are being cropped or are otherwise vegetated. On Figure 7.1a, the areas in green correspond to cropped areas. The fields which appear yellowish are generally bare soil, although urban areas tend to be similarly colored. Discrimination between very lightly vegetated areas and some bare fields is rather poor, but somewhat better than on any of the individual images of the multiband.

Figure 7.1b, despite its smaller scale, allows the best discrimination of vegetated and bare fields. Both possess one major disadvantage. The superimposed images are out of registry or alignment, causing a significant loss of detail and reduced capability to detect exact boundaries. Thus, in Figures 7.1a and b, identification of urban areas, discrimination of tree crops from others, and any more detailed identification is impossible. With the correction of this problem, the potential for more accurate identification appears to be great.

Electronic enhancement of three frames of 70 mm multiband photos was conducted by I<sup>2</sup>S to complement the optical enhancement of the multiband imagery. Of the resulting images, two appear to be quite useful, particularly in comparison to the simultaneous CIR image. One enhancement

was designed to simulate the CIR image (Figure 7.1d). Even when viewed at the same scale, the simulated CIR image is far superior to the original (Figure 7.1c). There is a significant improvement in the object-to-background contrast ratio, especially in agricultural areas. Those fields which have a light vegetative cover are not distinguishable on the original CIR image, but may be easily identified on the simulated image. The potential for this type of identification is greater than that of even the 1:60,000 CIR imagery. The only disadvantage in using the electronic enhancement is the loss of detail, particularly in urban areas. These areas may be identified at least as early on the simulated CIR as on the 70 mm CIR imagery. Attempts at more detailed identification may present accuracy problems.

Figure 7.1e, a false color rendition of tone density patterns of the 70 mm multiband photos, possesses the same kinds of attributes that the CIR simulation exhibits. Regions having high reflectance in the near infrared portions of the spectrum appear yellow and green. In general, this represents the cultivated fields with crops. However, there is the singular difficulty of discrimination between urban and some agricultural areas, as urban regions tend to possess rather high reflectivity. Nevertheless, the enhancement appears quite useful for the identification of agricultural regions. Again, as in the case of the CIR simulation, the lower resolution prevents detailed identification.

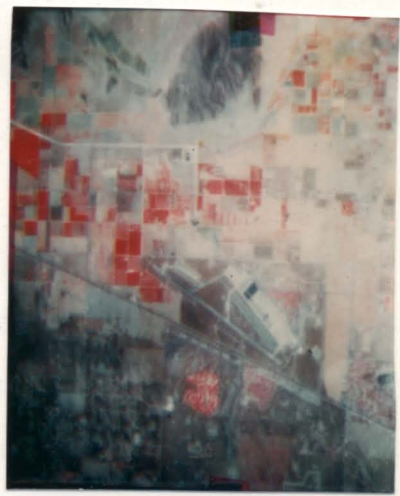
Generally, the use of enhancement techniques for the kind of land use mapping conducted in this project appears desirable. Images produced



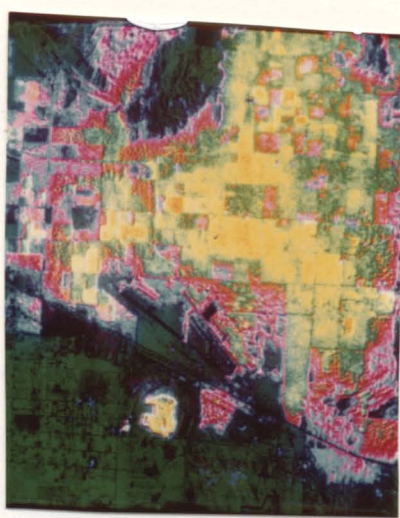
b



c



d



e

Figure 7.1. Three black and white multiband aerial photographs were used to produce the optical and electronic image enhancements shown above. The photographs used were: PAN + W.58 (green), PAN + W.25 (red), and B/W IR + W.89B (near infrared), each acquired simultaneously over the Perris Valley Study Area during NASA Mission 164. The U-shaped mountain area in the lower right corner of enhancements (a) (b) and (c) is the site of the future Lake Perris. Immediately northwest is March AFB. North is at the top of each photograph. Enhancements (a) and (b) are optical color enhancements of the multiband photographs. Each color image was created by projection through different filter combinations using the FRSL Optical Combiner to enhance distinctions between various landscape phenomena. (c) is a color infrared photograph acquired at the same time as the multiband photographs. (d) is an electronic color enhancement of the multiband photographs, created to simulate (analog mode) the color infrared photograph (courtesy I<sup>2</sup>S). (e) is an electronic color enhancement which provides greater interpret-

by optical methods, if properly aligned, possess the advantage of adding color, and therefore a greater capability for tone discrimination than the multiband. Resolution loss is held to a minimum since the image is not altered except to add color. Electronic enhancements, whether designed to simulate photography or present false color renditions, have the distinct advantage of improving object-to-background contrast ratios present in panchromatic films, thus facilitating easier discrimination of land use classes.

#### 7.3.2 Regional Information Systems

The development of equipment and methodologies for geographical information systems is a major topic of investigation at the University of California, Riverside. These investigations and developments have for several years been supported by sources other than NASA. Because of the successful applications of the information system equipment and techniques being developed, and because of the increasing need for the present and future NASA-California Grant investigations to handle large quantities of regional data, it is important that the two studies increasingly be more closely integrated. Several of the present studies, reported herein, have already made use of the system to various extents. A complete discussion of the system is not included here, but may be in the future as further integration occurs.

A recent technical report by Nichols, "A Demonstration of the Use of the Grid System Utilizing Multi-Source Inputs", is included in the present discussion because it provides a basic framework within which the

relevant uses of remotely sensed data in a geographic information system can be viewed. Although Nichols' study was not directly supported by NASA, it is based on the use of NASA photographic data (Mission 128B) and applies important concepts to a portion of the study area for NASA sponsored investigations being conducted at the University of California, Riverside.

Nichols demonstrated the use of a grid cell digital system when seeking to integrate data derived from high altitude aerial photography (or spacecraft data?) with other sources of information, e.g., topography, geology, vegetation, transportation, land use, etc. The system has the capabilities of data storage, retrieval, and manipulation. Further, a regional data bank file possessing spatial characteristics can be displayed with computer graphics and manipulated in the computer. For regional information systems to utilize as input any remotely sensed data, primary factors must be considered: resolution and regionalism. Obviously the two needs are ambivalent; consequently a compromise which minimizes the adverse effects of both must be sought.

Resolution for remotely sensed data inputs must be considered for two reasons. First, the image must provide sufficient detail to be useful for the inventory of the desired data, i.e., identifying transportation arteries, counting dwelling units, etc. Second, the resolution must be compatible with the desired fidelity of the inventory. A perfect survey is not necessary and often is impossible, even with ground survey methods, but the inventory data must be adequate for use in whatever application is chosen. Regionalism of the remotely sensed data is dictated, however, by the data rectification needed in order to reconcile the remotely sensed

data with the various other types of data inputs. It is also dictated simply by the desire to minimize data handling.

Nichols considered the requirements of resolution and regionalism and the utilization of remotely sensed data to develop location analysis methodologies. The application he chose to demonstrate was a model for regional park location in a study area east of Riverside, California. The area covers a wide variety of land uses, ranging from dense urban areas to agriculture, to mountainous open spaces. Perhaps the singularly most peculiar aspect of the study area is that it is bisected by the San Bernardino and Riverside County line. As such it has been a neglected area in open space and resource planning by both of the county planning agencies. Another reason for choosing the area is its "open space" nature. With public opinion demanding more rational urban development and more preservation of open space, it seems illogical to let such a prime area be ignored. Lastly, the area was chosen as a matter of practicality, for there was adequate NASA high altitude aerial photography covering the full area.

A grid overlay, based on the UTM system, was divided into grids of one-ninth kilometers, with each grid square thus encompassing approximately 27 acres. Data were interpreted from 1:100,000 color infrared aerial photography (Mission 128B) and combined with various ancillary information available from maps and other data sources. Several maps of the study area were then produced; Map 7.2 shows several examples. Map 7.2A shows population gravity; dark areas represent unpopulated areas with high population attraction, blank areas are populated. Map 7.2B shows accessibility; dark areas represent high inaccessibility and blank areas are "through" arteries.

Map 7.2C shows slope gradients; dark areas represent steep slopes. Map 7.2D shows the park location suitability composite, derived from all available data sources; dark areas represent high suitability.

Photos at scales larger than 1:100,000 were generally concluded to be inadequate for such a study because they did not provide the overall view necessary for regional information systems. Scales between 1:100,000 and 1:120,000 appeared to most adequately meet the conditions for compromise between the factors of resolution and regionalism. Scales smaller than 1:120,000 would be appropriate only if resolution requirements could be satisfied.

### 7.3.3 Monitoring Rural-Urban Transitions

#### Introduction

A preliminary investigation of one Riverside researcher, now completed, concerns the use of synoptic remotely sensed imagery for monitoring regional change (i.e., evolving rural patterns) in which urban land use successions can be predicted ahead of their actual development. This is a study in urban dynamics that has both practical and theoretical values. Urban and regional planners thus can foresee transition problems and monitor them as they develop. Students of urban morphology can observe the processes of rural to urban transition and land use succession.

#### Background and Procedure

The study began one year ago with a slightly different objective. Synoptic imagery was to be used in examining freeway impacts on agricultural land use, the expectation being that agricultural uses would change as anticipation of the freeway rose, as the actual construction proceeded, and as the route finally was completed. It was expected that labor and





A

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B

Map 7.2. (A) Population gravity. Dark areas represent unpopulated areas with high population attraction. Blank areas are unpopulated. (B) Accessibility. Dark areas represent high inaccessibility. Blank areas are "through" arteries. (C) Slope gradients. Dark areas represent steep slopes. (D) Park location suitability composite. Dark areas represent high suitability.



capital inputs to land would be intensified to raise productivity in keeping with higher carrying costs for rural land now taxed at urban rates. Instead, the phenomenon of factor disinvestment, or the minimization of factor inputs to land was observed. Sinclair described this phenomenon in a recent journal article, "Von Thünen and Urban Sprawl", (Annals of the Association of American Geographers, Vol. 57, 1967), but he did not test it empirically nor did the few other investigators who observed it analyze its causes. Examples of disinvestment patterns and their origins are yet unclear. Rather than a progressively more intensive production-factor-use-agriculture approaching an urban fringe in accord with the 150 year-old Von Thünen theory (which suggests that land rent appreciates from locational utility, and that land uses are ordered by their ability to pay these rents and the transportation costs), the opposite case prevails. Land use patterns are suboptimal because urban proximity clouds the long-run planning horizon and forces fringe land owners to adopt short-run plans. This is particularly true in dynamic situations, e.g., when a major transportation route is constructed. Production factor use is minimized because labor earns higher returns in the city; capital has higher return in land speculation or in investments other than farming. Land, as a consequence, is farmed without much capital or labor input, and such extensive uses as grazing, and the farming of barley and other field crops prevail in areas "clouded" by urban proximity.

An excellent site for examining disinvested agriculture is the route of the Pomona Freeway between downtown Los Angeles and eastern Los Angeles County through the Walnut Valley, which was basically rural in 1955 when

freeway plans were first announced. A study of the evolution of land use in this region is contained in Technical Report T-71-5 supported by NASA and Project THEMIS. Subsequent reports will test this modification of Von Thünen theory in other urban fringe situations, and will attempt to isolate those urban growth factors that account for these patterns. Other cities as they are selected, will be studied both in the field and by NASA photo coverage and will be subjected to the change detection, recording, and interpretation methods established earlier. Allowance will have to be made for different agricultural peripheries, urban growth histories, and other peculiarities of individual cities.

The research method in the study was simple and straightforward. Aerial photographs were used to compile land use maps for six periods before and after the completion of the freeway (1953, '58, '60, '65, '69 and '71). After the complete land use of the earliest period had been mapped, only change was recorded on subsequent maps. Area measurements were recorded for each period so that a current compilation and land use map could easily be constructed. By a materials-balance technique, types of land use input to and output from the rural-urban conversion process were recorded, and studies were made periodically of the nature of these events (with a civil or political division overlay, this can be done for small areas). Parcel histories could be determined, but in most cases they are obscured when the land use does not conform to property lines. The object was to examine whether a set of events of intensification and/or disinvestment is a precursor of land use succession. Events may differ because of site characteristics and, by the amount of prior investment into land, the peculiarities of the geographical situation can be considered.

From this determination it was shown that Sinclair's thesis applied in the test site in that (a) a disinvested agricultural zone exists, (b) the zone was widened because the freeway was built, and (c) a somewhat predictable sequence of events did take place in the conversion of land from rural to urban use which may take place in other areas. Further, it was demonstrated that this is easily recorded with a number of research tools, particularly that of the remote sensor.

#### Photographic Requirements

Photographic requirements for such a study are neither strict nor liberal. Timing the overflight is important for the sake of seasonality among agricultural patterns. Resolution is much more important. For example, demonstrating a decision to intensify production to derive higher returns that offset rising operational costs requires imagery that can resolve crop types in the field, e.g., recently mowed alfalfa is often confused with some types of row crops. This is not necessary for other patterns, particularly those that are urban in nature.

The NASA Mission 164 color infrared photography used for the latest periodic survey was available at 1:60,000 and 1:120,000 scales. The larger scale imagery has generally proven more useful in determining field boundaries than the 1:120,000 scale imagery. Ground resolution at either scale is generally not fine enough to determine row crops (except trees) and it has therefore become necessary to classify vegetable crops with field crops in 1971 (crop types, cropping patterns and "crop calendars" should be established for each area). The 1:60,000 scale imagery has thus far proven to be the most useful data acquired during Mission 164 for the present needs and purposes of this study. Lack of sidelap causes increased

interpretation errors where it is necessary to use this smaller scale imagery.

Film emulsion is also important. Color infrared film is preferred to normal color and to black-and-white films and, given the future higher platforms to be used for this research, the haze penetration capability of an emulsion should be considered strongly. Color enhancement techniques may enable identification of crop types, but if human photo-interpretation is required this would defeat the speed and accuracy benefits available with larger scale photography, with or without color.

### Results

The study area is a five-sided figure, topographically defined by the highest summits of two hill masses which enclose the relatively narrow Walnut Valley (Map 7.3). Parts of three and all of a fourth incorporated city lie in the study area but most is still unincorporated. The orientation of the study area follows the route of the freeway; as such, its dimensions are approximately eleven miles east-west by seven miles north-south. It includes 37,023 acres (14,989 hectares) of mixed land uses, with agriculture and vacant land predominating (Table 7.2).

Urban land uses succeeded agriculture on 4,719 acres (1,910 hectares) of agricultural land, and only 1,076 acres (467 hectares) of vacant land was absorbed by urbanization. With that in mind, nearly twice as much urban land use and population can be sustained by absorbing the remaining agricultural land, thereby raising the holding population of the region (Statistical Area 26.0, Los Angeles County Regional Planning Commission) to approximately three times its present figure (179,000).

Land use changed within agriculture in a number of ways before urban

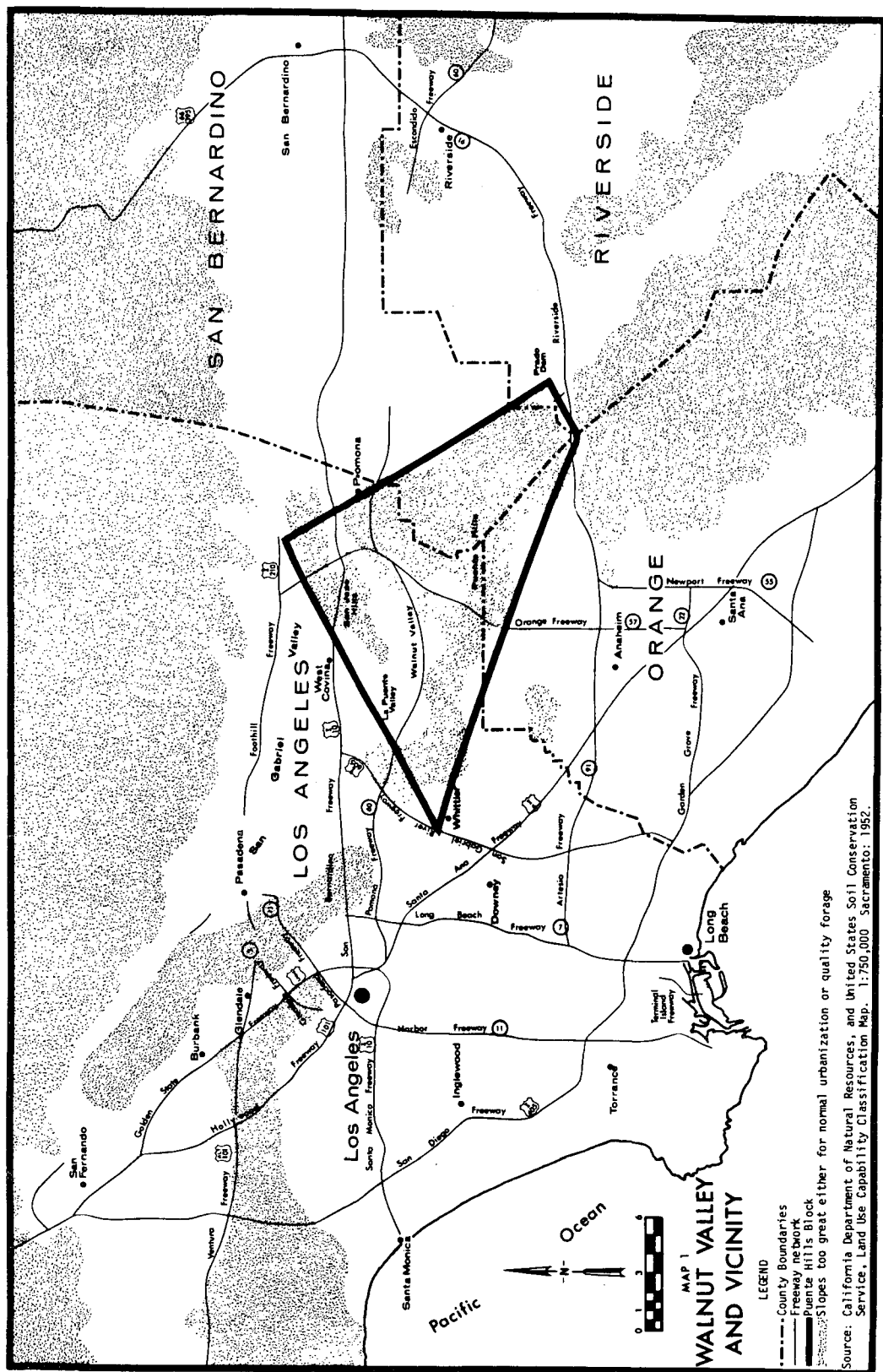


Table 7.2

PERIODIC LAND USE IN THE WALNUT VALLEY AREA OF SOUTHERN CALIFORNIA  
(in acres)

Source: Aerial Photo Interpretation

Land Use Type	Date of Survey					
	1953	1958	1960	1965	1969	1971
<b>AGRICULTURE</b>						
Citrus	868	507	342	143	137	137
good			831	297	102	102
fair	1,314	1,154	154	348	231	231
poor	91	50	113	137	140	140
abandoned	24	29				
Walnuts						
fair	1,207	554	280	69	36	36
poor	134	304	443	321	257	251
abandoned	40	80	46	98	72	62
Avocados	13	13	13	13	13	13
Field Crops	3,020	3,393	3,334	2,988	2,753	2,542
Row Crops	285	340	325	170	178	178
Mown Grasses	3,157	2,991	2,879	2,147	2,127	2,092
Grazing	3,200	3,018	2,915	2,795	2,762	2,760
<b>TOTAL AGRICULTURE</b>	<b>13,353</b>	<b>12,439</b>	<b>11,675</b>	<b>9,511</b>	<b>8,808</b>	<b>8,544</b>
<b>URBAN</b>						
Residential	228	821	1,726	3,554	4,016	4,417
Industrial	66	215	324	523	740	755
Commercial	6	9	9	56	84	154
Recreational	0	0	39	341	363	363
Institutional	156	156	166	279	373	373
Agricultural	230	277	267	287	264	264
Vacant	321	517	361	306	456	502
<b>TOTAL URBAN</b>	<b>1,007</b>	<b>1,999</b>	<b>2,892</b>	<b>5,446</b>	<b>6,294</b>	<b>6,828</b>
<b>VACANT</b>	<b>22,663</b>	<b>22,595</b>	<b>22,456</b>	<b>22,056</b>	<b>21,919</b>	<b>21,651</b>
<b>TOTAL LAND USE</b>	<b>37,023</b>	<b>37,023</b>	<b>37,023</b>	<b>37,023</b>	<b>37,023</b>	<b>37,023</b>

land use (residential, industrial, institutional, etc.) succeeded. Five types of decisions were made by land owners, known as:

1. Intensification: the increase in factor use as in the replanting of citrus, the enlargement of a dairy, or the planting of row crops in place of field crops.

2. Direct conversion: the change of productive agriculture to urban use, as in the replacement of good citrus groves by a subdivision.

3. Succession: the following of low-productivity agriculture by urban use, as urban barley fields or deteriorated citrus is followed by a subdivision.

4. Disinvestment in Lieu: the following of productive agriculture by a less productive agriculture, as when citrus is replaced by barley farming.

5. Disinvestment: the allowing of agricultural uses to deteriorate in situ. Land owners adopted these strategies in different proportions depending on the urgency with which they perceived conditions for land use change. Population growth was continuous in Southern California through the first decade of this study period and slowed only recently. Walnut Valley growth, however, was an exception to this general case since growth was great. Freeway announcement, construction, and completion stages are fairly well defined in the rate of housing constructed as in land owner decision-making processes. Owners tended to adopt land sale enhancement strategies (disinvestment in lieu) in periods of "booming" growth and disinvestment strategies when sales (lending rates, financing availability, etc.) were off. The intensification of agricultural land use was a much less important decision than expected. In broad terms, the expanding

Los Angeles fringe through Walnut Valley triggered land use change to urban uses and agricultural decline through disinvestment stages. Urban land use succeeded when land was "properly prepared", i.e., already cleared of arboreal crops to minimize land development costs, or where terrain was easy to develop. Some land holders found buyers and sold acreage with producing crops despite agricultural opportunity costs, and converted to urban uses by the direct conversion method.

The Walnut Valley study suggests that decision-making may follow both optimizing or maximizing and also "satisficing" planning principles. Timing the proper strategy or development decision requires matching interim land use that has a rate of return commensurate with the discount rate on undeveloped urban land with every inflection in the change of the discount rate. That is, every influence, e.g., freeway construction, that affects the discount rate affects interim land use decision-making. Optimizing strategies presuppose a sufficient range of possible interim land uses and do not recognize the multiplicity of factors determining actual land use patterns. In unique settings these factors range from chance events in some remote historical period to current decisions made for understandable but non-economic reasons. "Satisficing" (Simon, Models of Man) is a behavioral or psychological response to planning in a complex situation where the decision-maker lacks information, access to production factors, etc., and his alternatives are restricted. "Satisficing" provides for a land use that is "good enough" given the strictures of the particular situation.

Urban and regional planners need to recognize the ways in which urbanized landscapes evolve. They make few land use maps, owing to their cost



by traditional field survey methods and, as a consequence, a man's utility is limited to a historical or illustrative value, and its major value, when used synoptically to observe economic patterns rearranging themselves, is lost. The application of remote sensing data can help change the situation. Urban fringe problems are widely recognized: (1) disparate land usage and the gross inefficiency of any distribution system that services disconnected development whose conversion is not phased incrementally; (2) from an agricultural investment view, blighted landscapes have a social cost in the loss of interim use returns due to "clouded" planning futures and the disinvestment strategies which they prompt; and (3) agriculture produce also incurs a higher transportation cost. While a policy regulating rural-urban land use conversion in increments of growth is lacking in the United States, this synoptic method points out where land owners may initiate a conversion long before the necessary formal procedures are begun. Planners may then take corrective measures. By remotely observing tangible land use evidence of decision-making, the synoptic, photographic interpretation and other techniques employed here married to urban growth theory (land economics and locational theory) greatly facilitate the planning of the urban fringe.

#### 7.3.4 Mapping Montane Vegetation

##### Introduction

A previous NASA-funded study produced a discussion on the application of mapping montane vegetation in southern California (Minnich, Bowden, Pease, 1969). The study included several vegetation maps of the San Bernardino Mountains in areas where color infrared aerial photography had been acquired from NASA and other sources. The original photo-interpretations

were made by Richard A. Minnich. Subsequent to NASA Mission 164, Minnich re-examined the earlier effort, evaluated the more complete photographic coverage of Mission 164, and made certain revisions to the vegetation map. The following addendum to the earlier study provides a number of technical revisions as well as extension of the area mapped. No effort is made here to reproduce the revised map. It is hoped, however, that this may be done in the future.

Addendum to "Mapping Montane Vegetation in Southern California with Color Infrared Imagery"

Parts of the original vegetation map of the San Bernardino Mountains are revised from interpretation of color infrared imagery of subsequent research missions, including NASA Mission 164 (April 1, 1971; scale 1:60,000 and 1:120,000) and coverage of the Big Bear Fire (Western Aerial Survey, April 7, 1971; scale 1:16,000). Areas of major revision are along the Mill Creek ridge eastward to Kitchin Peak (formerly not covered), the Lucerne Valley scarp, and the Bear Fire area.

Superior resolution of new imagery also resulted in more detailed mapping over much of the study area. However, more sophisticated mapping could have been accomplished originally, but this was prevented in publication for cartographic reasons.

Since the north-south flight lines in Mission 164 at a scale of 1:60,000 failed to overlap, a portion of the Mill Creek ridge -- from Oak Glen to Raywood Flat -- that area is mapped at a scale of 1:120,000 and therefore has reduced detail. Due to simplicity of vegetation, along the Lucerne Valley scarp to the north, there was negligible loss of information from small imagery scale. More information is gained in the Big Bear Fire

area due to better scale and resolution of the 1:16,000 scale imagery.

Two changes are made to the Plant Classification:

1. Lodgepole-Limber Pine Forest (Pinus Murrayana-Pinus-flexilis) in the dwarfed or krummholz state ( $LP_K$ ) is mapped as a contrast to erect forest (LP).

2. Terrace chaparral ( $C_{TER}$ ) is changed to hard chaparral ( $C_H$ ) since both categories are dominated by similar flora.

A survey of the new imagery flown to assess Big Bear fire damage, characterized spectrally by deficient infrared enhancement but excellent resolution, allowed for comparison and evaluation of original mapping problems related to vegetation types. Changes in the revised map reflect these same problems which are described below.

Because desert plants are small and display no consistent color signature, desert vegetation can be interpreted with least reliability, particularly in ecotonal areas where Desert Chaparral ( $C_D$ ), open Pinion-Juniper Woodland ( $PJ_0$ ), and Juniper-Joshua Woodland (JJ) coalesce (e.g., in the Whitewater, Mission, and Morongo drainages, and in the Ord Mountains). Necessary reliance on definite color signatures for identification of Coastal Sage Scrub and Chaparral types, instead of physiognomy, made the original mapping of these plant groupings suffice despite improvement of resolution. However, additional groves of Knobcone Pine (Pinus attenuata,  $CE_{kb}$ ) and Coulter Pine (Pinus Coulteri,  $CE_{cp}$ ) in chaparral were identified and mapped. Since the exaggerated crown structure of Big Cone Douglas Fir (Pseudotsuga macrocarpa,  $CF_{bs}$ ) could be resolved on the old imagery, little additional information was obtained on this chaparral conifer. No misidentification of chaparral conifer species was evident on the original

mapping either by direct or habitat recognition (Coulter Pine) as stipulated in the report.

The distribution originally shown for the Montane Coniferous Forest (PF) is considered accurate although minimal detail on internal floristic composition was obtained from enhanced resolution. Areas of Montane Coniferous Forest with Sugar Pine (Pinus Lambertiana) as subdominant, however, were identified by recognition of the similar but less exaggerated crown structure of this species compared to Big Cone Douglas Fir. Little hope exists in the possibility of mapping areas dominated by either Ponderosa Pine (Pinus ponderosa), Jeffrey Pine (P. Jeffreyi), White Fir (Abies concolor) or Incense Cedar (Libocedrus decurrens). Further, in the original imagery photographed during the summer growing season, the sclerophyllous evergreen tree oaks (Quercus chrysolepis, Q. Wislizenii), and Black Oak (Q. Kelloggii) exhibited similar color signatures. This fact, in combination with poor resolution, originally prevented discrimination of the three species. The problem was partially solved during the recent coverage when deciduous Black Oak was not in leaf. As a result, the sclerophyllous oaks can be observed as subdominants in primarily lower, drier portions of the Montane Coniferous Forest. Contrasts in the old and new imagery also make certain the identification of stands of Mountain Mohogany (Cercocarpus ledifolius) as a brush undercover in drier margins of the Montane Forest. These new distinctions in Montane Coniferous Forest are not mapped for lack of time and complete photographic coverage.

Areas mapped as Lodgepole-Limber Pine Forest (LP) are considered accurate due to obvious morphological differences of these subalpine trees

compared to adjacent Montane Forest conifers. On the other hand, deficient resolution of the original imagery prevented their being mapped as subdominants along the upper elevational margin of Montane Coniferous Forest. Color signatures on the new imagery indicate that the three dominants of Timberland Chaparral (Arctostaphylos patula, Castanopsis sempervirens, and Ceanothus integerrimus) are individually mappable.

The mapping of Pinion-Juniper Woodland (PJ) is considered excellent by simple recognition of definitive physiognomic characteristics of the dominant trees as in the case of Lodgepole-Limber Pine Forest. Areas of "dense" Pinion-Juniper Woodland (PJ<sub>D</sub>) are less reliable because of problems in discerning Western Juniper (Juniperus occidentalis) from Pinion Pine (P. monophylla). Due to poor resolution, only areas of Juniper whose prevailing size is greater than Pinion Pine could originally be mapped under this category. Further, individual Junipers cannot be identified consistently on the basis of color signature. Larger scale aerial photography may resolve this problem. Areas of Great Basin Sage species (GB) which form a dominant undergrowth in wetter margins of Pinion-Juniper Woodland (PJ, PJ<sub>D</sub>) and occasionally in drier parts of Montane Coniferous Forest (PF) can now be mapped beyond the present indicated distribution to dry basins and flats adjacent to Baldwin Lake and Rose Mine.

The mapping of areas composed of marginal ecotonal forests characterized by admixing of tree species from Chaparral and Montane Coniferous Forest -- in particular Dry Forest (DF), Transition Forest (TF), and Interior Oak Woodland (C<sub>WD</sub>') -- may have errors. Confusion rests not so much on the uncertain identification of conifers as on that of the oaks discussed above. In areas where it has been determined that Black Oak is

not in foliage, stands of Dry Forest can be separated from large groves of Coulter Pine in Emergent Oak Chaparral ( $CE_{cp}$  found in  $C_{WD}$ ) by discriminating between Quercus Kelloggii from Q. chrysolepis, respectively. Areas of Dry Forest can also be separated from Interior Oak Woodland by identification of Q. chrysolepis or Q. Wislizenii, with Q. Kelloggii absent. Boundaries between Dry Forest and Montane Coniferous Forest may be inaccurate because of difficulty in consistently separating areas of Coulter Pine from Montane Forest Conifers due to physiognomic similarity. Even with enhanced resolution, the best interpretive technique is to observe tree shadows to determine whether branches extend to the ground or if the main trunk is visible, characteristic of mature Coulter Pine and Montane Forest conifers, respectively. Improved resolution also resulted in the separation of Transition Forest into two distinctive types. On steep north facing slopes and south facing slopes above 6000 feet elevation, areas of Transition Forest with Big Cone Douglas Fir mixing with Montane Forest conifers could be mapped by clear-cut identification of Big Cone Douglas Fir. However, areas of Coulter Pine also could be found mixing with Montane Forest conifers on usually steep south facing slopes. The boundary between this form of Transition Forest and Montane Coniferous Forest is quite adequate because of the nearly synonymous upper elevational limit of Coulter Pine and the sclerophyllous oaks (Q. chrysolipis, Q. Wislizenii), the latter being easily identified on color infrared imagery by their bright red color signatures. Reliance on this technique is supported by the observation that these oaks may occur without Coulter Pine in drier portions of the study area, but not conversely. Therefore, if sclerophyllous oaks are present on a high south facing slope, one is

nearly assured of the presence of Coulter Pine, with certain verification possible by study of branch structure from shadows. The combination of sclerophyllous oak with Coulter Pine could be classified as Conifer Emergent in Chaparral ( $CE_{cp}$ ), but in higher elevations Montane Conifers are likely to be in association, justifying the Transition Forest classification.

The chief problem encountered with color infrared imagery in vegetation analysis of montane areas of Southern California is in finding proper combinations of infrared enhancement, and resolution. The original imagery is perhaps too "red" causing difficulties in the identification of species exhibiting strong red records, such as the oaks. Conversely, color infrared enhancement is beneficial in the mapping of plant groupings with poor red records, such as chaparral. Poor resolution of the old imagery prevented direct identification of plants in terms of their physical structure. When color signatures were indefinite, poor resolution forced identification of species from the pattern displayed by a group of individuals in space and not from a study of the individual itself. Thus, if homogeneity of spatial arrangement of the group were not consistent throughout the range of the species, mapping would be impossible. For example, lack of homogeneity in physiognomy and plant arrangement made mapping of Mountain Mahogany, Western Juniper, and Great Basin Sage species prohibitive, even with spot verification in the field. The reds on recently acquired imagery are periodically washed out due to overexposure, sun angle problems, and film inconsistencies. This is compensated for by excellent resolution, so that direct identification can be carried out. However, while the introduction of new imagery revealed possible inaccuracies of the original map, the revised map is not materially different. This indicates the original, and therefore both maps are basically

accurate, except perhaps in areas dominated by Desert Woodland and marginal ecotonal forests where minor boundary errors may occur. More importantly, the plant classification contained in the original report remained stable. Plant combinations which appeared to be consistent vegetation groupings in the study area remained as status quo, despite the addition of the newly acquired aerial photography. This result supports the view that color infrared aerial photography offers a new alternative in the recognition and classification of plant groupings not only in the San Bernardino Mountains but also in other areas.

#### 7.3.5 Urban-Regional Land Use

The Riverside-San Bernardino-Ontario Study Area is one of twenty-seven selected urban test sites presently under study in an experiment in urban analysis and change detection using remote sensing techniques. The program is being coordinated by James Wray, Geographic Applications Program (funded by NASA's Earth Resources Program), U.S. Geological Survey. What is conceived is an original multi-faceted urban area atlas, presenting land use maps compiled from high altitude aerial photography (1:120,000 scale) and ancillary data. Mosaiced photography will be overlain by a land use map and a statistical area grid which then can be easily compared with attached population and housing census information. All information will be presented in a graphic as well as statistical format.

Locally, not all of this study area can be presented cartographically within the text of the Urban Atlas. Only a portion covering a variety of landscapes is mapped. This includes the central cities of Riverside, San Bernardino and Ontario, as well as many adjoining urban, agricultural and undeveloped and montane natural areas. One area of greatest likelihood of



dynamic change in future years is in the general vicinity of the Perris Valley, including Lake Perris. The total study area at present is approximately 2,000 square miles, as shown on Map 7.4. Beyond the presentation of land use and ancillary data, other methodological objectives are also sought.

As the principal contribution to the project by the researchers at UC Riverside concerns land use information, they are investigating additional methodological possibilities. After the best available high altitude photographic and other land use information has been acquired, the effort is to develop improved interpretation, presentation, and analysis techniques in developing a data base useful in other research studies and applications. This, in effect, is the development of a Geographic Information System. As many as 74 land use categories will be interpreted from aerial photography acquired during Mission 128B (May 1970, 1:50,000 and 1:100,000 scales) and Mission 164 (April 1971, 1:60,000 and 1:120,000 scales). These land use categories will later be processed and converted to 17 basic land use types for the Urban Atlas (see Table 7.1). The initial interpretation at greater detail is justified owing to the fact that this effort will not be terminal, but rather an on-going land use study.

Upon completion of the interpretation, land use areas will be digitized (x-y coordinates) by 4-hectare cells and recorded in format for computer processing, storage, and manipulation, as well as image and map rectification. The same statistical areas will be used as during the 1970 Census of Population. Additional high altitude aircraft or spacecraft (e.g., ERTS) remotely sensed data may then be evaluated and interpreted in a similar



Map 7.4. Location Map outlining preliminary study area for mapping regional and urban land use from high altitude aerial photography and ERTS-A data.

manner in the future to determine the location, kind, and intensity of land use change and development.

More than five years of experience and accumulated remote sensing technology, and improved research methods and techniques serve to permit this investigative team to pursue the objectives beyond the requirements of the USGS-GAP program inputs simultaneously. This is advantageous not only to refine that input but to advance the state-of-the-art of synoptic, change-detection monitoring of urban areas. In this sense, the Urban Atlas project is opportune because it is now perceived as a critical milestone in our research methodologies. Familiarity with local urban-rural-wildland environments should improve the accuracy of, and simplify, land use information extraction, as well as permit researchers to explore more fully automated data handling techniques for developing methods of periodically updating data bases.

Land use interpretation and mapping is now in progress. Each 9" x 9" image will be mapped in its entirety on overlays at a scale of 1:120,000. Each overlay will then be placed beneath the 9" x 9" transparency as a guideline of the digitizing of discrete polygons (x-y coordinates). This method permits the technician to digitize land uses without the interference of the overlay (with generally heavy lines). Image-map rectification, areal computations, as well as mapped distributions and thematic maps can be produced using computer graphics. These historical records -- a grid map, a cartographic map, and the photograph -- can then be available for the next synoptic survey. (Examples of these types of products are shown in Figure 7.2 A, B.) Progress to date has included the assemblage of necessary photography, maps, and other data sources, initial programming

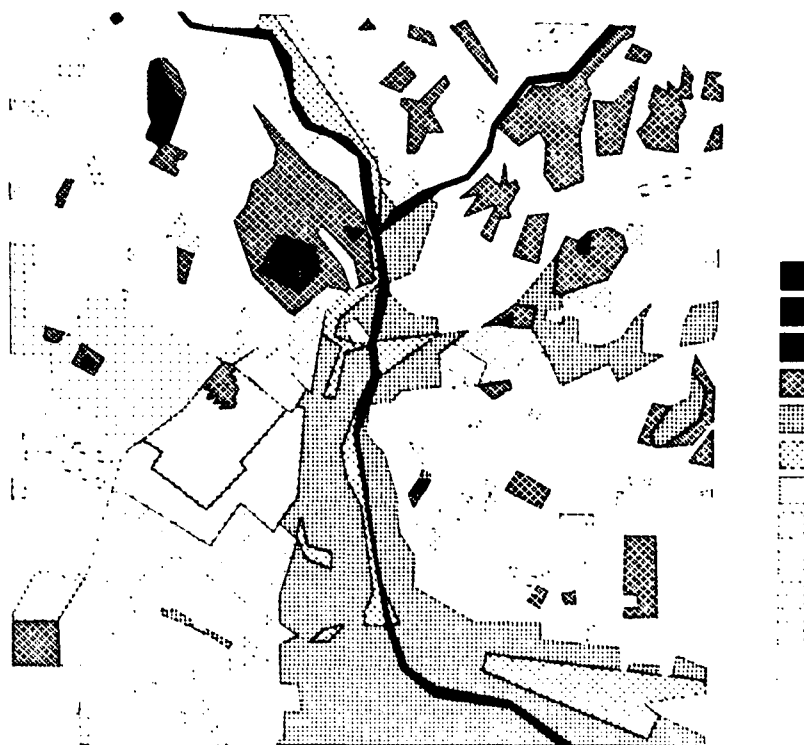


Figure 7.2A. Sample preliminary computer produced land use map of central Los Angeles and the "CBD". The original data source was 1:60,000 scale aerial photography. (Classification codes are omitted in this preliminary example.) This map required one hour to outline, one hour to digitize (x-y coordinates), two hours for data preparation, and 20 minutes computer plotting time. Examples of grid maps which could be produced for the same area are shown in Section 7.3.2 of this report.





for conversion of interpreted data for computerized mapping, and initial photo-interpretation of general land use categories.

#### 7.3.6 Remote Sensing of Environmental Quality in Relation to Land Management

Remote sensing of the environment, when properly applied, is a technique to monitor environmental quality. The phenomena sensed is that which influences quality and includes numerous things that man can experience. Many of the phenomena in man's experience are unlikely to be subject to remote sensing, but they cannot be ignored. In other words, a system of remotely sensed indices of environmental quality may be developed and used effectively to inform but should not be used to dominate policy.

In a like manner, resource managers have been negligent in failing to fully use remote sensing techniques as a means to aid future land management. All too often, detection of effluents, evaluation of already blighted areas or spot checking of conditions is as far as remote sensing gets used. Unfortunately, newly formed political and popular fronts for the assessment and improvement of environmental quality run the risk of using ill-informed and ill-considered popular action that will alleviate some problems detected by remote sensing and aggravate other, more serious problems.

It seems clear that no policy regarding environmental quality, whether remote sensing is involved or not, could be meaningful if it took less than a regional perspective or outlook and often a world-wide view is desirable. It also seems clear that when dealing with land use and/or land management anything less than predictive models for future use and preventive models for future quality deterioration are necessary.

Land does not exist in any definable "pure" form -- geologically or

ecologically -- and land pollution means departure from a normal rather than departure from a pure state. Because the land is both diverse and subject to natural or cultural change, the key problem is to determine if the changes are within a broad "normal" range or if they are degradative. And, can degradation be identified, classified and judged? Is it harmful to man and nature?

A land environment is always subject to pollution be it volcanic dust, deer manure or disposed beer cans. Most pollutants are soon broken down or integrated into the environment through decay, burial, settlement and so forth. Over the eons, absorption, oxygenation, and consumption easily clear and disperse small amounts of pollutants. Interaction in the environment among land, air, water and biomass tends to stabilize or control excessive pollution. Except in geologic time spans, little alteration occurs on the natural landscape. However, man has recently upset the cycles of erosion, deposition, decay and regrowth by impressing on the total environment a new and demanding cultural landscape.

Cultural or human pollution of the land has expanded exponentially in the last two centuries. Streams have become sewers unable to dispose or control the material dumped into them. Rural areas are collectors of discarded junk and urban cities are ribbons of refuge and garbage surrounding dismal housing and uncontrolled development. At the same time, water and air have also been polluted and ecological systems disturbed and interrupted. The magnitude and intensity of the problems have become so much greater in recent years that they have blossomed into major political issues. The problems have also generated conflicts penetrating all segments of the economic system.

At the present time, limited government action is the rule to be followed. Standards are to be set, action ordered and so forth by various local, national or international governmental agencies. There are very few guidelines for either the private citizen or private industry to follow to be a lesser land polluter. The concept that the only social responsibility of business is to use resources and engage in activities designed to increase profits so long as the business stays within the rules of the game (Friedman, 1962) places the burden on government to set the rules.

However, damage to the land arises from so many sources that only intense cooperation by private and public factions can produce the slightest positive result. And then the index we use to measure the results may also be misleading.

The most widely used index is the Gross National Product (GNP) which represents the goods and services produced in a given period and moving through market channels. As the name implies, GNP is "gross" because it disregards the conventional kind of depreciation, the wearing out of plants and equipment, etc. However, tax deductions are allowed for depreciation to business for such declines. Yet, nobody depreciates the land, allows for wear out or pollution in any form. The GNP does not take account of depreciation of environmental quality. In fact, increase in GNP is often at the expense of resources. If pollution, for example, eroded rather than bolstered the GNP, government agencies and private industry may well have cleaned up the environment years ago (Janssen, 1970).

Unfortunately, so much of our pollution is unmeasurable in money terms such as effect on GNP. How does one value a beer can on the landscape



when the production and consumption of the beer and container added to the gross national wealth. Somehow a change in indices is necessary before individuals or agencies can take action to remove or retard pollution. One may detect a sugar beet field full of salinity, but to advise the farmer on action or guidelines to remove or reduce salinity is a different situation, especially if it lowers his annual income.

In the less clearly defined realm of culturally altered landscapes our mobile population is capable of spoiling one region after another. Except possibly in Alaska, so little "wilderness" remains that, even if it all were preserved, it cannot serve a population that seeks it out as a relief from its culturally blighted landscapes of normal residence. The potential for degradation of the quality of living is all around us. First noted in the deteriorating environments of the urban scene, it is now prevalent in all parts of western societies' landscape (Aschmann, 1971).

Within the capability of remote sensing lie three critical and applicable possibilities as summarized from Aschmann (op. cit.):

1. The capability to inventory our entire national territory in terms of environmental characteristics that affect the quality of human living.
2. Early detection of slight but progressive environmental changes.
3. The identification of patterns and associations of variable and disparate environmental features, both natural and cultural, that society can associate with desirable or undesirable environments.

The first of the three above is most critical. The least elastic of the nation's (and the world's) resources is land and land space. Space on, above or below the urban concentrations is of greatest value yet the non-urban space remains critical to our natural resources but is being

progressively pre-empted.

It seems worthwhile to inventory in some detail the spaces in and around urban population concentrations to determine what fractions remain and in what land use. How much of the nations land is in "single-purpose, pre-emptive land use"? What are the evolving patterns?

Urban and regional planners need to recognize the ways urbanized landscapes evolve. They make few land use maps, owing to their cost by traditional field survey methods, and as a consequence a map's utility is limited to a historical or illustrative value and its major value, when used synoptically to observe economic patterns rearranging themselves, is lost. The application of remotely sensed data can help change the situation. Urban fringe problems are widely recognized: (1) disparate land usage and the gross inefficiency of any distribution system that services disconnected development whose conversion is not phased incrementally; (2) from an agricultural investment view, blighted landscapes have social cost in the loss of interim use returns due to "clouded" planning futures and the disinvestment strategies it prompts; (3) agricultural produce also incurs a higher transportation cost. While a policy regulating rural-urban land use conversion in increments of growth is lacking in the United States, a synoptic method comparing a series of photographs can point out where land owners may initiate a conversion long before the necessary formal procedures are begun. Planners or policy makers may take action when they observe agricultural patterns entering an urban-transition process. By remotely observing tangible land use evidence of decision-making, the synoptic, photographic interpretation and other techniques married to urban growth (land economics and locational theory) greatly facilitate the planning of

the urban fringe (Goehring, 1971).

Evolving land use and management change, can be detected early with the use of synoptic remotely sensed imagery. Goehring (1971) found evidence that urban land use successions can be predicted several years ahead of their actual development. Urban and regional planners can foresee transition problems and where they occur, while they develop. Whether they can or will do anything about the problems depends on policy.

Basically, detection of environmental quality should mean early detection of indices or surrogates so that action can be taken. When blighted districts are fully developed they are easily identified visually by almost any observer. We need to recognize earlier the signatures of blight or declining environmental quality. We need to recognize those combinations of physical landscape and cultural management that are associated with and precede blight.

During the 1960's, we established that impoverished rural environments, urban housing quality, land deterioration and classes of socioeconomic conditions were definable from remote sensing methods. All of our research efforts, mostly in Chicago, Asheville Basin, and southern California were checking the system to see if we could compete with ground based observers in doing land use, land and housing quality, inventory and evaluation of existing land resources. Now it is time we used our capabilities to project the future of land use and guide land management in a meaningful way to protect environmental quality.

However, one proceeds with the above if he knows, or thinks he knows, what is a desirable environmental quality. It seems that man needs, in addition to food, clothing and shelter, numerous other items to be satisfied.

The most important is diversity. A monoculture or monolandscape seem to be unattractive, whether they are continuous, similar suburban homes or flat, horizon seeking grain fields. Yet, there is no extensive documentation on such important indices as (1) change (2) boundary or (3) individualism. Nor is there historical documentation of the relation of the above three to attitudes or environmental quality. Mullens, working with imagery of Los Angeles, found he could class urban housing quality in relation to middle class income by examining three factors -- vegetation, litter and open space.

In a like manner, hazards to living (earthquake, fire, flood, tidal wave, landslide, etc.) are identifiable in a regional and often local sense. All of these are predictive, rather than after the fact. They are not monitoring of past events that deteriorate man's happiness but are projections of from where the deterioration can come. Of course, such items as housing density, industrial location, and recreation area use are well within the realm of being remotely sensed.

In the 1970's, those of us who have looked at remote sensing applications for a long time, are starting to realize some of the actual potential. An example might be the determination of environmental land quality prior to the invasion of an interstate highway plus the prediction of what it will do -- not just locally but regionally and nationally. Aschmann states that the concept of the "right and wrong side of the track" has been with us for a long time. But remote sensing should be able to furnish us the data to foresee an area that will become the "wrong side of the track" when and if certain phenomena occur.

Of course, information taken from remotely sensed data is only useful

as a surrogate of what the real scene is. This is the case where both privacy and social contacts are sought on alternate bases. Crowdedness, or the lack of it, of things on the land is most certainly detectable by remote sensing. What is not distinguishable is the desire for privacy or social contact. However, as one builds the totality of environment from those data bits of remote sensing, often a picture or some insight is formed. Land use, transportation facilities, energy supplies, recreation opportunities, or more simply "the role of man's activities on the land" are readily subjected to analysis with remote sensing methodology.

Occasionally, there are surprises such as finding out that urban vegetative condition sensed with color infrared photography is directly correlated with quality of housing and neighborhood income. On the other hand, some apparent sensors are not as useful as the engineering might lead you to believe. Thermal infrared scanners at one time seemed to be a potential tool for night-time traffic monitoring but as yet have failed to make the step.

There has been too much publicity on how remote monitors can detect crop vigor, thermal outflows, stream effluents, forest fires and others. It is time we brought the need for land use planning, prediction of land and environmental quality and the capabilities of remote sensing together. In a nation that has the technology and hardware to sense every acre of land but no regional, state or national land use policy, the time for both is overdue.

There is no question that remote sensings greatest contribution is in the detection and inventory of land use. No other method of survey or analysis comes near to remote sensing when land use data is desired. As

has been stressed earlier, once the land use is known, then the real or potential "land pollution" can be described. Just as important is that land use is a prime key to existing and potential air and water pollution.

Overall, the "state-of-art" of remote sensing is technically advanced to the point of being very useful for detection of land pollution. The major drawback is "what" to detect and "how will it effect policy?" In effect, before any evaluation as to "benefit-cost" can be made, costs that have previously been part of the social or cultural pollution of production must be subtracted. As a result, standard economic series such as GNP will have a rather bleak look for a long time. If pollution control efforts should expand significantly, new guidelines will be needed to interpret what the statistical series are telling us and what the remotely sensed data are telling us about economy and environment. Once the policy changes are made, the new data will not be comparable to data in use today. As a result, remote sensing of the environment will play a much more significant role in early detection of pollutants and serve as a method of monitoring policy and regulation enforcement.

#### 7.4 FUTURE STUDY

During the past six months several significant accomplishments have been achieved in regards to future studies. The Perris Valley Study Area investigations are essentially complete for the present. A data base for a large area has been established which will allow further monitoring for land use change and development using future remotely sensed data. The Regional Information Systems study has provided significant methodological developments in a small area which can now be expanded over large regions to enable rapid and accurate semi-automated analysis of environmental

resources and land uses, with automated data storage and manipulations. The Urban-Rural Transitions study yielded important theory and data for interpreting and analyzing these areas of dynamic land use change using remote sensing techniques. The Addendum to "Mapping Montane Vegetation..." utilized and critically tested the applicability of high altitude aerial photography for the mapping of discrete wildland resources with positive results and techniques. And finally, the analysis of land pollution in southern California using remotely sensed data has summarized our learning effort in understanding very important and complex landscape phenomena.

Each of these efforts contributes to the study of Urban-Regional land use, which is in the initial stages of development and data interpretation. Classification, data formatting, data processing, data display for maximum utilization, and multi-faceted data analysis are some of the problems which have been dealt with, all of which are present in the land use interpretation and analysis of large and complex urban-regional areas. While several of the other studies will continue (e.g., Perris Valley, Urban-Rural Transitions, land pollution, and environmental quality), all the problems and developments will be represented in the Urban-Regional Land Use project. Furthermore, this project is designed so that boundaries of the study area may be enlarged at any time to include other areas, such as the southern California coastline, when it becomes important or opportune to do so. Investigations will also continue to prepare for and utilize pre-ERTS simulation photography and ERTS data, as they become available, to map, analyze, and update those environmental phenomena present on the landscape and remotely sensed data.

7.5 STUDIES PUBLISHED, SUBMITTED FOR PUBLICATION, AND IN PREPARATION,  
DECEMBER, 1971

Published

The following papers have been published or have been issued as Technical Reports (Interagency). Items 3 and 4 were wholly supported by the NASA Grant. The remainder were partially supported by this grant, including data requirements.

1. Aschmann, H. H. 1971. Prolegomena to the remote sensing of environmental quality. The Professional Geographer. XXIII, 1. January. pp. 59-63.
2. Bowden, L. W. 1971. Remote sensing of the Baja California coast. In: Proceedings of the 2nd Coastal and Shallow Water Research Conference. University of Southern California. Los Angeles. October.
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6. Brooner, W. G. and J. B. Bale. 1971. Land use map of Palm Springs from high altitude aerial photography. Western City Magazine. March. p. 21 & p. 24.
7. Brooner, W. G., R. M. Haralick and I. Dinstein. 1971. Spectral parameters affecting automated image interpretation using Bayesian probability techniques. In: Proceedings of the 7th International Symposium on Remote Sensing of Environment. University of Michigan. May 17-21. 1929-1950. Also: Technical Report T-71-2. Department of Geography, University of California. Riverside, California.
8. Brooner, W. G. and D. S. Simonett. 1971. Crop discrimination with color infrared photography. Journal of Remote Sensing of Environment. 11, 1. October. pp. 21-35.



9. Goehring, D. R. 1971. Monitoring the evolving land use patterns on the Los Angeles metropolitan fringe using remote sensing. Technical Report T-71-5. Department of Geography, University of California, Riverside. October.
10. Johnson, C. W. 1971. Computerized land pattern mapping from mono-imagery. In: Proceedings of the 7th International Symposium on Remote Sensing of Environment. University of Michigan. May 17-21. Also: Technical Report T-71-3. Department of Geography, University of California, Riverside.
11. Nichols, D. A. 1971. A demonstration of the use of the grid system utilizing multi-source inputs. Technical Report T-71-4. Department of Geography, University of California, Riverside. August.
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15. Sullivan, A. E. and W. G. Brooner. 1971. Remote sensing of chaparral fire potential: case study in Topanga Canyon, California. Technical Report T-71-1. Department of Geography. University of California, Riverside. March.

#### Presented Papers

Items 1-4 were wholly supported by the NASA Grant. Item 5 was partially supported by this grant, including data requirements.

1. Bowden, L. W. 1971. The use of remote sensing to study the impact of urbanization on environmental quality in southern California. Presented at: Applications of Remote Sensing to Urban and Regional Planning. Department of Engineering, University of Wisconsin. Madison, Wisconsin. October.
2. Bowden, L. W. 1971. Remote sensing of urban environments. Presented at: Department of Urban Planning, California Polytechnic College. November 19.

3. Bowden, L. W. 1971. The view of earth from space. Presented at: Kaiser Foundation, Southern California Permanente. Fontana, California. November 20.
4. Coleman, V. B. and W. G. Brooner. 1971. Remote sensing of land use change and development: Perris Valley, California. Presented at: Meetings, Association of Pacific Coast Geographers. Victoria, British Columbia, Canada. June.
5. Pease, R. W. 1971. The remote sensing contribution to climatology: present and future. Presented to: Physical Geography Panel, Meetings of the Associations of American Geographers. Boston, Massachusetts. April.

#### Submitted for Publication

The following papers or contributions, partially supported by the NASA Grant, have been submitted for publication.

1. Brooner, W. G. and J. E. Estes. Color enhancement techniques for environmental information. To: Commission on Geographical Data Sensing and Processing, International Geographical Union.
2. Johnson, C. W. The design of a computer oriented land use mapping system. To: Commission on Geographical Data Sensing and Processing, International Geographical Union.
3. Pease, R. W. Data acquisition with false color film. To: Commission on Geographical Data Sensing and Processing, International Geographical Union.

#### Reports in Preparation

The following studies, partially supported by the NASA Grant, are in preparation; progress is discussed in this report.

1. Bale, J. B. and J. Minch. Coastal geomorphology and shore classification of Baja California del Norte, Mexico.
2. Departmental staff. Models and analyses of urban/regional land use: Riverside-San Bernardino and vicinity.
3. Minnich, R. A. Inventory and analysis of Montane Fire: a computer model from the Bear Fire.

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## CHAPTER 8

## DIGITAL HANDLING AND PROCESSING OF REMOTE SENSING DATA

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## 8.1 INTRODUCTION

An important part of the Integrated Study of Earth Resources carried out by the University of California is the combined use of all available sensing devices which provide information of interest to earth resource scientists. Two considerations influence the use of multisensor data. Firstly, the data collected in each of several different bands on each of several different dates often must be analyzed in various combinations in order to maximize the information available from such data. Secondly, with the launch of the ERTS A satellite, sets of multisensor data in an electronic format will become available to our project as one of the major data sources. Thus a significant component of our work is designed to develop the efficient or optimal use of a large amount of remote sensing data the better to study specific earth resources. Three approaches are used in the analysis of the available data:

Human Photo Interpretation

Electronic Image Enhancement

Automatic Data Processing

These three approaches complement one another and are all pursued within our study. In this part of the progress report we describe the work done to date on the digital handling and processing of remote sensing data, more specifically as it refers to Electronic Image Enhancement. For this work the data processing facility being established as part of the University of California program emphasizes man-machine interaction rather than bulk processing of data. It uses as a central processing element a digital computer and thus the development or use of data processing algorithms becomes principally a problem in computer software development. With this approach it becomes possible to make use of the very extensive digital computation facility already available at the University of California. By the acquisition of a very modest number of specialized computer peripherals, an extremely versatile and flexible facility is being made available to the program. This digital signal processing facility, also used on other NASA-sponsored image processing work, is described more fully later on in this report and will be connected this year to the CDC 6400 digital computer of the Campus Computer Center.

Personnel from the Department of Electrical Engineering, Davis Campus and from the Department of Electrical and Computer Science at Berkeley are concentrating on the question of multisensor data combination and electronic enhancement.

## 8.2 WORK PERFORMED DURING THE PERIOD COVERED BY THIS REPORT

The progress to date on our part of the integrated study can be divided into the following broad categories:

1. Detailed specification of plans for the digital processing facility which is at the heart of our current and future activities.
2. Assembly and construction of the digital image processing facility.
3. The conduct of preliminary work on means and programs for data acquisition and handling and developing of a system for use in programming various digital image processing tasks.
4. The conduct of preliminary work on digital signal processing algorithms of broad relevance to feature enhancement of remote sensing data.

### 8.2.1 Digital Processing Facility

The major share of our time since our last progress report has been devoted to the development of a digital processing facility. Progress has been very substantial and in some aspects, in advance of our anticipated schedule.

For our work we make use of an IBM 1800 Computer which has been modified by the addition of an array processor designed and built for the specific task of digital signal processing. The array processor speeds up by a factor of 20 a number of operations of interest in

signal processing. Thus this small digital computer has a substantial computing power for the type of processing of prime interest to the integrated project. Further the IBM 1800 will be connected by a high rate data link to the CDC 6400 of the Computer Center at Berkeley. Thus we have a highly desirable situation in which data acquisition, simple data processing and image display can be done in a dedicated facility available for real time and interactive work, while a large computing facility and a large software system can be used for large computations and elaborate processing.

A diagram of the overall system configuration is shown in Figure 8.1. In the following section we report on our progress in the assembly or design and construction of several of the computer peripherals required for our work.

#### Image Storage and Display System

After careful examination of the alternative ways of displaying multispectral images processed digitally at a suitably high rate (30 frames per second), we decided to use as a storage and output device an analog video disk. This video disk stores black-and-white images or color images and can output any of them repeatedly at the standard television rate. Thus a substantial file of images processed by different techniques can be stored and displayed in rapid succession on a cathode ray tube monitor for comparison by an observer. This valuable feature should reduce in many cases the need for extremely rapid processing.

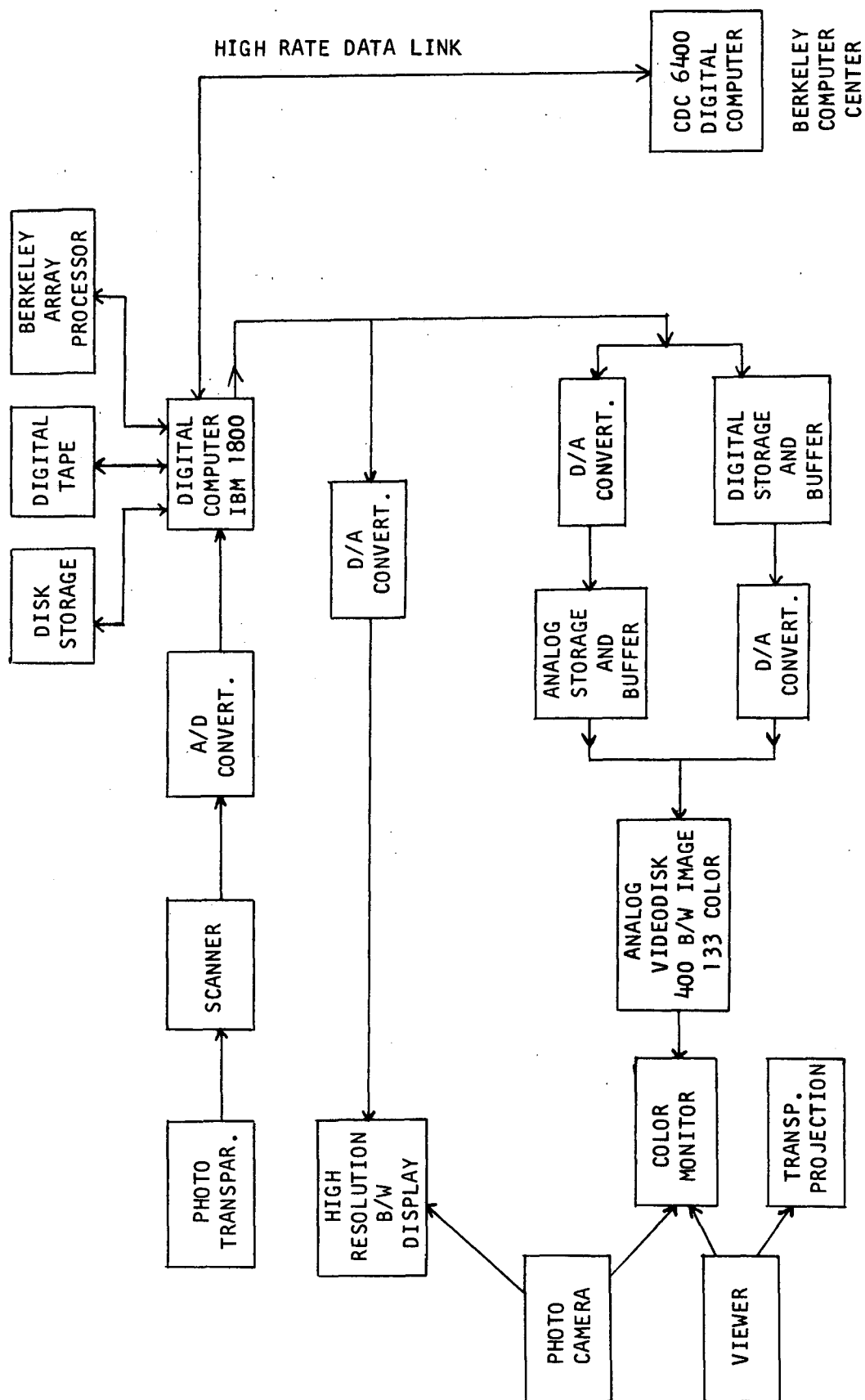


Figure 8.1 Digital Image Processing Facility



### A. Video Disk

The video disk selected for our facility is an analog storage device manufactured by Data Disk Incorporated. The video disk is capable of holding 300 frames of 525 line double interlaced, 30 frame/sec video data. Each frame occupies one track of a 14"-1800 rpm nickel-chrome disk. The mode of operation of the video disk, for color display is shown in Figure 8.2 and described below.

1. The computer writes the 3 color components of (electrical signals) an image (Red, Blue, Green) one after the other on 3 tracks of the video disk.
2. Once the three color components are stored in the disk they are read simultaneously and in perfect synchronization.
3. The three color components drive the three electron guns or the control grids of a television color monitor. Thus a full color image is generated 30 times per second for flicker-free viewing.

The video disk provides synchronization signals, coming from a clock track, to the Digital-Analog buffers and to the B/W and color monitors.

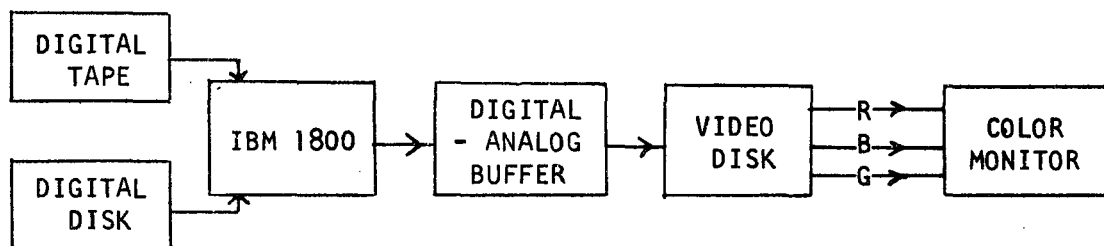


Figure 8.2

The need for the Digital Analog buffer shown in Figures 8.1 and 8.2 arises because of the gross mismatch between the output capability of a digital computer and the signal bandwidth requirements of the analog video disk.

For the video disk the signal bandwidth assuming an 8 bit gray scale is approximately  $60 \times 10^6$  bits per second which is faster than the I/O channel bandwidth of most digital computers; in particular, it is faster than the data channel of the IBM 1800 computer. It is therefore necessary to provide some form of rate conversion when outputting from the digital computer to the video disk. We have chosen two different methods of scan conversion. The analog method is based on the Hughes Model 639 Scan Converter described below. A digital method of buffering is also being built and should provide images of substantially higher quality. The digital approach is also described in this section.

#### B. Analog Buffer

The analog buffer is a Hughes Model 639 scan conversion memory. The heart of this device is a storage tube with a resolution of 1200 lines which will store for several minutes an image with grey scale, written at an arbitrary slow rate. In operation, the IBM 1800 computer will build up an image on the storage surface, point by point, by providing to the scan converter the x,y coordinates and the intensity value to be stored. Our program currently requires 60 seconds to build up an image. Once the image is stored it can be read out continuously 30 times per second and thus stored immediately on the video

disk which provides synchronization signals. The stored image is only of fair quality and in particular the gray scale is not very wide. After experiencing considerable difficulties, due in part to the fact that this product is new on the market, and after making some modifications of our own design, we now have this unit in operation and able to provide images of adequate quality for viewing.

### C. Digital Buffer

Video Interface Buffer (VIBE). A simplified block diagram of the digital buffer (VIBE) is shown in Figure 8.3. We describe the operation at the functional level only, reserving detailed description to a user's manual.

#### 1. 16 line (8 x 8192 bits) MOS shift register buffer

The heart of the digital buffer is the 8K byte MOS shift register memory (Intel 1403 @ 1 cent per bit) capable of a two phase shift rate of 5 mhz. We multiplexed the shift registers using a 4 phase 10 mhz. clock to obtain a data rate of 100 ns. per byte. Of the 6.35  $\mu$ s in a horizontal line, 51.2  $\mu$ s is used to display 512 sample points at 100 ns per point and 12.3  $\mu$ s is used for a horizontal synchronization pulse and blanking. The 8K buffer is partitioned into 2 banks called Bank A and Bank B. Alternate lines of data from the computer are routed to Bank A or Bank B so that Bank A contains up to 8 lines of data for one field of the interlaced frame while Bank B contains 8 lines of data for the alternate field. Consequently interlacing is performed by hardware and is transparent to the user. Data are obtained from the 1800 in 16 line slices at the rate of 1 byte/ $\mu$ s. The placement of

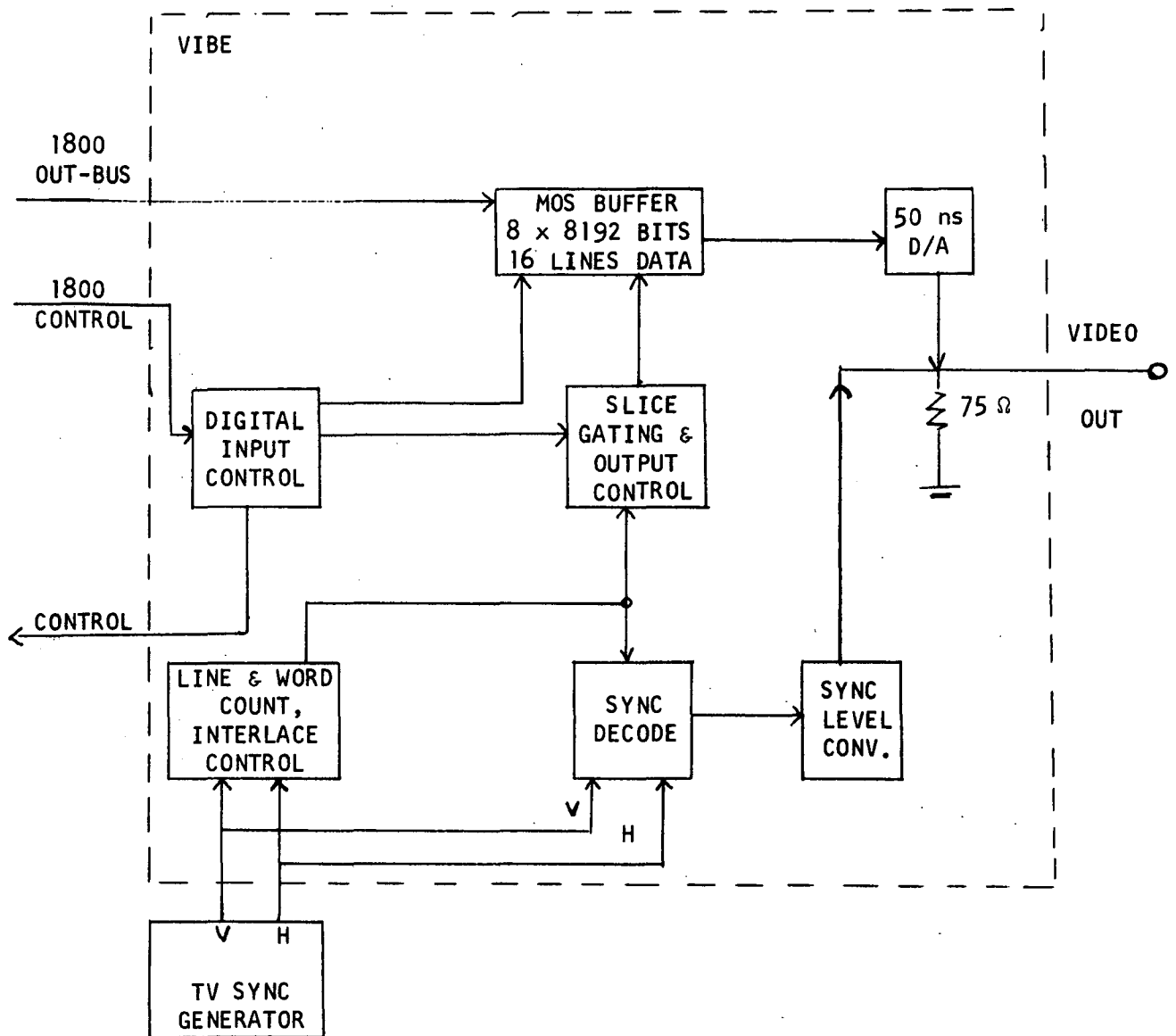


Figure 8.3 Simplified block diagram of VIBE

the slice as well as the size of the slice is under program control. Thus a flexible method of analog signal synthesis is obtained using digital techniques capable of achieving significant gray scale resolution (8 bits and up) at TV rates.

## 2. D/A converter and slice gating output control

The digital slice stored in the 16 line buffer is read out under slice gating output control when the disk location corresponds to the desired slice location. Two output sequences are placed on the disk per revolution corresponding to the 2 interlaced fields. D/A conversion occurs at 100 ns rates using a 50 ns D/A converter.

## 3. Digital input control

Digital input and analog output from the MOS buffer occur at mutually exclusive times. The input is under the control of the digital input control logic. The IBM 1800 computer initiates the transfer of digital data to the VIBE. Subsequent control of data access is handled by digital input control on a cycle steal basis at a rate of 2 bytes/2  $\mu$ s. The MOS buffer is shifted at a 2  $\mu$ s rate to provide "essentially synchronous" transfer although the interface is designed for non-synchronous operation. Although channel priority assignments are made so that a cycle steal request should be honored within 2.5 ms, provisions are made to signal an overrun if a request is not acknowledged within 2.5 ms. The 2.5 ms service rate is a condition imposed by the dynamic MOS shift registers for data refresh. The digital control is complicated somewhat by this requirement, which is the price we paid for an "inexpensive" memory.

#### 4. Line and word counter, interlace control

Referenced to the once-per-revolution clock on the disk, we partitioned the disk into 525 sections corresponding to the 525 horizontal lines. The partition is made in such a way so that EIA TV signal constraints are observed. The counting and interlace control logic is provided so that we may accurately synthesize a 512 line picture using 16 line slices. The entire picture construction process is expected to take 6-10 seconds.

#### 5. TV sync generator and sync decode

A sync generator under crystal control is used to furnish vertical and horizontal sync pulses for overall system synchronization. The sync pulses are also furnished to the VIBE for proper data output synchronization. The sync decode logic generates an EIA sync and blanking signal which is added to the D/A output to form the ultimate video. Care is taken to avoid signal contamination from the sync pulses by logically disconnecting the sync signal from the video except during the blanking interval.

The construction phase of the VIBE is approximately completed.

#### Electromechanical Scanner

Some images that we will process will be already scanned and available on magnetic tape. However, in many cases it will be desirable to work with images that other workers have been experimenting with and which are available only as photographic slides. For this reason, it is essential that our digital processing facility

be capable of scanning such images and reading the scanned image into the computer for storage on disk or magnetic tape. Consequently, we have constructed an electromechanical scanner. This scanner has a pair of horizontal rails and ball-nut lead screw; on these rails are mounted a pair of vertical rails and ball-nut lead screw, with a small rigid aluminum platform running on the vertical rails. The lead screws are turned by digital stepping motors which can position the platform in steps of  $1/500''$ , to an accuracy of a fraction of a step. The scanning mode of the platform is as follows:

- Accelerate downward up to terminal speed
- run N steps downward at terminal speed
- decelerate vertically to rest step M steps horizontally
- accelerate vertically upward to terminal speed
- run vertically upward at terminal speed
- decelerate vertically to rest
- step M steps horizontally etc.

By carefully choosing the acceleration and terminal speed, it is possible to scan 1500 steps per vertical line at a rate of slightly more than one vertical line per second.

Attached to the moving platform is a lens barrel, PIN photodiode, and battery operated FET preamplifier. The photodiode chip is  $1/50''$  square. Thus with a lens barrel giving magnification of  $\alpha$ , the scanning resolution is  $(1/50\alpha)$  inches.

A program has been written that enables the IBM 1800 computer to:

- (1) move the scanner according to the above scan mode

- (2) take the output of the preamplifier, sample and quantize to a digital number and
- (3) store the digital samples in a core until a number of lines have been collected, then read onto a disk, reordering the lines that are scanned upward.

The hardware and program were completed in August, 1971. With only minor electronic errors, which have been corrected, the scanner functions exactly as had been hoped for. With only modest lighting, the electronic noise is negligible. To date the scanner has only been tested with 1 to 1 optics, giving a resolution of  $(1/50)''$ . However, lens barrels with 5 to 1 and 10 to 1 optics have been completed in the past week and should be tested soon. When this is done, we will scan a fine line grating to see if we can obtain the hoped for resolution (1000 element scan lines on a 2" high negative).

#### Display Monitors

We have acquired a good quality 14" Conrac black-and-white monitor. Although our intention is to make use of a high quality color monitor we are making use for the present of an inexpensive 12" Sony Trinitron Television Receiver. We have modified the set to have access directly to the video color signals. This simple approach provides us with an inexpensive color monitor for check-out of programs and algorithms.

#### High Speed Data Link, IBM 1800 - CDC 6400 (H.SIC)

The design philosophy behind the high-speed communication link is an attempt to combine the high speed multi-precision computational



power and large core memory of the CDC 6400 with the graphic output facilities of the IBM 1800.

The CDC 6400 'A' machine is primarily a batch oriented computer system. This system's main resource is its ability to perform rapid multi-precision computations on large amounts of data that are stored entirely in its fast memory. The CDC 6400 system, however, lacks the provision for user-program interaction on a real time basis and lacks sufficient real time picture display equipment.

On the other hand, the IBM 1800 system is ideally suited for interactive real time picture displaying, but lacks the computational power of the CDC 6400.

A combination of the IBM 1800 process controller with the CDC 6400 computer system will create a more versatile computer system.

The communication link is to be the primary data transmission path between the IBM 1800 and the CDC 6400. In normal operation, a picture file will be sent from the IBM 1800 to the CDC 6400 where it will be processed and then sent back to the IBM 1800. Here the file might undergo auxiliary IBM 1800 processing and then be placed on the display screen for a closer visual examination. At this point the person who is directing the processing might choose to try the same set of CDC 6400 processing programs with a different set of data or try another set of CDC 6400 processing programs with the same data. In both cases, the data transfer procedure will start again and the processing sequence will be repeated. Using this type of interaction,

rapid turn around can be achieved and the user's train of thought is not broken. Real time decisions such as this might take as little time as a few minutes or as long as an hour. In any event, it is necessary to make the data transmission rate as fast as possible to minimize the computer time needed to transmit the large picture file (for instance  $512 * 512$  word) and also to minimize the time that input and output buffer space needs to be available in the IBM 1800 and CDC 6400.

The data buffers in the CDC 6400 may be as large as 100,000 (OCTAL) 60 bit words. If four IBM 1800 words are packed to one CDC 6400 word, this space is more than enough to store a complete  $512 * 512$  picture file. In the IBM 1800, the memory is only 20,000 (OCTAL) words of which about 6000 (OCTAL) words are taken up by the TSX Executive. This leaves 12,000 (OCTAL) words for both the user program space and buffer area. Therefore, the absolute maximum data buffer space available in the IBM 1800 is less than 10,000 (DECIMAL) words.

Data are originally stored in a slow speed bulk storage device and must be made readily accessible before they can be transmitted between processors. The number of data words that can be manipulated in an IBM 1800 record is at most 10,000 words (160,000 bits). This amount of data can be stored or fetched in an average of 320 milliseconds. Assume that we want an order of magnitude difference between bulk data retrieval time and data transmission time. It is necessary to transmit 160,000 bits in 32 milliseconds: a transfer rate of

5000 bits/millisecond. Data transfers which are made to and from the CDC 6400 are done in multiples of 12 bits because the CDC 6400 peripheral processors are 12 bit machines. Therefore, the transfer rate must be on the order of  $5000/12 = 417$  words/millisecond or  $.42 \times 10^6$ , 12-bit, words/second. An upper bound is placed on the transmission speed due to the limitations on the speed at which the CDC 6400 peripheral processor can shuffle data (a maximum rate of one 12-bit word every microsecond). Cable delays of 1.5 nanoseconds per foot further reduce the maximum transmission speed. In this case, the transmission cable is 1,000 feet long and introduces a 1.5 microsecond delay per direction. For reliability and simplicity of construction a data transmission method was chosen which requires a confirmation signal from the receiving end and therefore a cable delay of  $2 \times 1.5 = 3$  microseconds is introduced into the communication link. A rather conservative transmission speed of 1, 12-bit word every 3 microseconds, a transmission rate of 333,000, 12-bit words per second, seems to be a practical upper bound for the data transmission rate of the communication link. This speed would allow a record to be transmitted in under 40 milliseconds. A complete picture file consisting of  $512 \times 512$ , 16-bit words is composed of twenty-five 10,000 word records. The total data transfer time would be  $25 \times 40 \times 10^{-3} = 1.0$  seconds. The total seek and data fetch time would be  $25 \times 320 \times 10^{-3} = 8.0$  seconds. Based on these calculations a complete file could be moved from one computer system to another in less than 10 seconds.

System specifications must include the form in which the data are to be transferred between processors. The IBM 1800 has 16-bit words;

the CDC 6400 has 60-bit words. This difference in word size introduces a number of problems. First, in the IBM 1800, fixed point numbers are represented with 16, 32, or 48 bits of precision; in the CDC 6400, fixed point numbers are always 60-bits long. Second, in the IBM 1800, floating point numbers are represented with 32 or 48 bits of precision and the exponent follows or precedes the mantissa; in the CDC 6400, floating point numbers are 60 bits long with a preceding exponent.

A useful interface must have the provision for easily converting from one computer system's number representation to the other's. To minimize the IBM 1800 and the CDC 6400 computer time associated with reformatting the transmitted data, a design choice was made to supply the interface controller with enough computational power to perform data conversion. This choice proved to be beneficial because it greatly increased the flexibility and growth potential of the communication link. To achieve the potential speed and advantages of such a communication link a sophisticated electronic device, under control of the IBM 1800 is being designed and built. The major part of the construction, which is at the IBM 1800 end of the link has been completed and will be checked out in the near future. Some software development and possibly some minor hardware procurement will be needed at the CDC 6400 end of the link and will be undertaken during the fall of 1971.

#### 8.2.2 Developing of a Picture Processing Programming System

Due to the large number of specific operations of interest in

our work it is necessary to provide a framework for the organization of user oriented image processing programs. To this end an image processing system is being developed.

That system consists of four components:

1. Monitor
2. Processing subroutines
3. User program
4. Disc update program

The components have the following functions:

The processing subroutines perform the actual picture processing, including such tasks as filtering and display. The user program consists of a sequence of statements used to cause the execution of a sequence of processing subroutines. The monitor interprets the user program, stores the information contained in the user program, allocates appropriate storage space for data files, and initiates execution of processing subroutines. The disc update program adds to the monitor portion of the discs all required information about a processing subroutine newly added to the system.

It is intended that the picture processing system will be a useful tool for studying a broad range of specific topics. Since it is always difficult to foresee in which direction the research will proceed as new methods are devised and tested, it is of paramount importance that the system be sufficiently flexible to change and grow as needed. In order to make the processing system as useful and flexible as possible, a number of desirable properties had to be

weighed and put in their proper place. The major considerations are listed here together with the reasons for their importance.

1. The system will be useful as a tool both for implementing working methods and algorithms and for interactively studying new approaches. Once a reasonable algorithm is obtained, it will be necessary to test it in detail. The non-interactive mode will be convenient for this testing. Until a reasonable algorithm is obtained, however, it will be very helpful to be able to study new ideas interactively.
2. System users will be required to have minimal familiarity with computers. Requiring less specific computer knowledge for use of the system will increase the number of potential contributors to the task of developing useful processing algorithms. Particularly the system's intended use as an interactive tool would be severely hampered by placing a programmer between the system and the user.
3. A wide variety of processing options will be available to the system user. These options will include, for example, various displays, filters, and transforms. Such options will provide the user with a great deal of freedom to assemble algorithms and test his theories.
4. It will be possible to add new processing options by following a set of simple and straightforward steps. This will facilitate increasing the system processing option repertoire while minimizing time wasted by the writer of an option learning the system's inner workings.

5. There will be a file management system that assigns and keeps track of the storage of data files. Because pictures of interest will often have many sample points (a quarter million is not unusual), massive amounts of data will be stored in such files on disks and tapes. The file management system will perform two functions: convenient manipulation of data files by the system, and easy access by the user to the files.
6. The user will not be able to alter the system monitor accidentally. The reason for this consideration is obvious.
7. It will be necessary to limit the time required for performance of the system. This is important because a user may be interested in an algorithm which consists of a large number of rapidly performed processing options. Then monitor functions could require a significant percentage of the overall processing time and thus severely restrict the system's usefulness as an interactive tool.
8. The programming language with which the system user will implement his algorithms will be sufficiently flexible to grow and change as new needs develop. This flexibility will limit time wasted in rewriting the programming language to meet unforeseen needs.
9. The system software itself will be written in such a way as to minimize the time required for making changes in the software when the original programmer has left the project. This is

essential since turnover among students is necessarily high while at the same time new developments may require changes in the system.

10. The system will have to be sufficiently simple that it can be implemented within a period of a few months. Research is already taking place in a number of areas, and it is desirable that the system be a useful tool for these ongoing investigations.

The need for such a system is already quite apparent from the difficulty we now encounter in using the large number of small programs which are already written. The constants on the individual programs which will allow their incorporation into a system are currently being specified. After this initial step all new programs will normally be incorporated into the system and a revision of non compatible programs will also be carried out.

#### 8.2.3 Programs for data acquisition and handling and for image enhancement and display.

A number of programs of general interest in the acquisition, reformatting, analysis, enhancement and display of images have been written. Since they form at this time an heterogeneous collection we shall not report on them in detail but describe them in the context of reports on specific applications. We shall point out at this time the broad areas into which these programs can be grouped.



### Data Acquisition and Reformatting.

Images and data available to us in digital form require some processing to facilitate their use in our digital processing facility. Some specific problems are images recorded in 7 track tape, number of points per line and number of lines not convenient for our mass storage devices, grey scale not suitable for analysis or display, etc. Flexible programs are required to handle some of these problems, including the problem of different file sizes and the reformatting of large files for ease of access.

### General Utility Subroutines.

These programs are necessary building blocks in the design of user-oriented programs. A listing of some of the programs now available will illustrate the type of operations these programs perform. In use, after the description has been given a set of parameters specifies completely the operation.

MOVE: Transfer picture files from one storage location to another for further processing or for permanent storage.

NLIN: Set up a table to map grey scale values into a distorted scale. Such a table is needed for instance for slicing the range of grey values.

FFT: One-dimensional or two-dimensional Fourier Transform. Useful in texture analysis, edge enhancement, etc.

DISP: Display a picture file by outputting x,y coordinates and intensity values of all points in the image. The output

display device may be a storage cathode ray tube (CRT), a precision CRT, the scan converter for video disk storage, etc. A number of options are available in this program according to the specific needs.

#### Specific Enhancement or Application Programs.

Several such programs, which make use in part of the subroutines described in the "General Utility Subroutines" section are of ultimate interest. We shall just describe two of these programs.

##### A. Constant intensity, color presentation of grey scale values.

The program maps grey scale values into colors for ease of interpretation. The mapping is easily described by referring to the diagram of Figure 8.4.

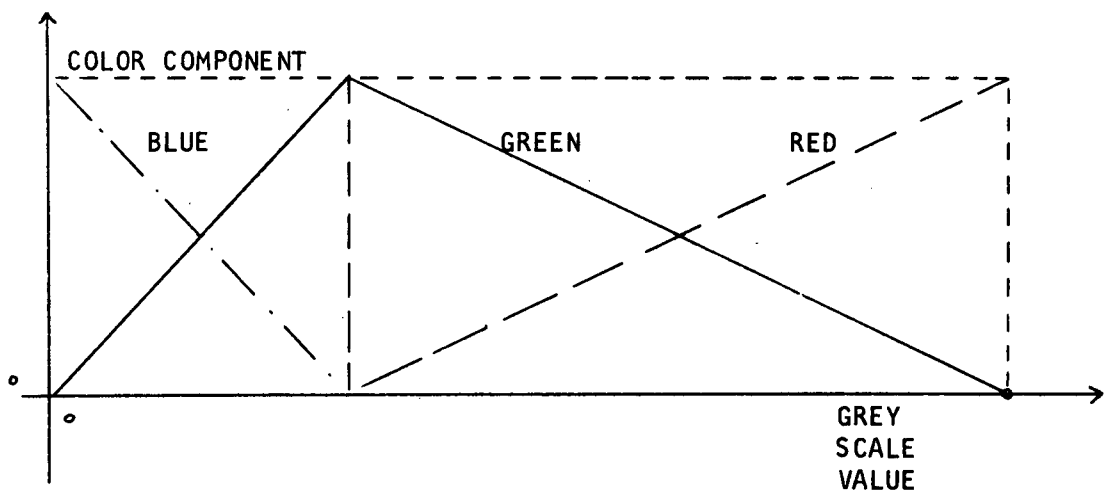


Figure 8.4

Each grey scale value generates 2 color components, either blue and green or red and green. Thus, for a complete black-and-white image, 3 images are generated. The 3 images are stored one by one on 3 tracks of the video disk and displayed in color. Thus intensity values will map into colors which range from blue for low intensities to red for high intensities, going through all intermediate values. This is a common approach to color mapping of grey scale values which can be used for any type of feature enhancement. Arbitrary color coding of adjacent grey scale values can be obtained by predistortion or slicing of the grey scale before the color map.

- B. We are now writing a program to enhance the vividness of colors. It is well known that in "high-flight" photography the colors of objects on earth become desaturated and thus less vivid to a viewer than on low altitude photographs. One remedial operation (which is simple to carry out on a digital computer) is to manipulate several spectral components at once in such a way that each of the colors of a color composite image becomes more saturated.

The programs just described are principally mentioned for illustrative purposes. We have also undertaken a systematic approach to image enhancement in an interactive mode which makes use of most of the data available to a viewer. This effort is just started and will

be carried out in the coming several months.

In October 1971 V. R. Algazi visited the Laboratory for Applications of Remote Sensing (LARS) at Purdue University and became acquainted with the activities and plans of the Laboratory in the areas of Data Handling and Automatic Feature classification.

Work relevant to our effort has been carried out by a Ph.D. student, Michael Ekstrom, of the Lawrence Livermore Laboratory. His work is not supported by the grant. However, that part of his work which deals with the numerical restoration of random images is applicable to some aspects of our projects.

N72-20352

## CHAPTER 9

### INVESTIGATION OF ATMOSPHERIC EFFECTS IN IMAGE TRANSFER

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The experimental and theoretical programs for this part of the investigation are well under way. The dual-channel polarizing radiometer designed and built on the project is now operational, and some preliminary measurements have been taken with it. Performance of the instrument fully meets the design specifications, and it is believed to be capable of higher precision in polarization and intensity measurements than any other instrument of its type in existence. Further details of its design and performance are given below.

A computer program has been written, but not yet completely checked out, for computing the effects of dust, haze, and other aerosol particles on the field of radiation emerging from the top of the atmosphere. By the use of various atmospheric models, it will be possible to study the sensitivity of the radiation field to parameters such as the size-frequency distribution of aerosol particles, real and complex parts of the index of refraction, and the vertical profile of the aerosol concentrations. A number of photographs have been taken with polarizing optics to obtain a

preliminary estimate of the advantage to be gained by the use of polarization for enhancing the transfer of images from surface to high altitude sensor in the actual atmosphere.

The main progress made so far on these tasks during the past year and the proposed work for the coming year are summarized below.

#### 9.1 INSTRUMENTATION

This investigation requires an instrument capable of measuring the intensity and polarization parameters of incident light rapidly with high precision. The dual-channel polarizing radiometer mentioned above is a computer-controlled instrument which satisfies these requirements. The instrument uses the photon counting technique for high-precision measurements of the intensity of light and its complete state of polarization (degree of plane polarization, degree of elliptic polarization, and orientation of the plane of polarization). Stepping motors and rotary solenoids are used for orienting the instrument and for the positioning of optical components (shutters, optical filters, calibration devices, etc.), thereby permitting complete computer control of instrument operation. Any type of scan pattern desired and any measurement sequence selected can be developed into a computer program, after which time the computer automatically controls the complete measurement program. In fact, the data are reduced to the physical variables of interest (intensity, state of polarization, etc.) on a time-sharing basis during instrument operation, so that the desired quantities are printed out on a real-time basis during the measure-

ment sequence. This not only eliminates all of the manual labor associated with data reduction, but it also permits decisions to be made on the basis of the data obtained.

The dual-channel polarizing radiometer is shown in Figure 9.1A and a closeup view, with the light-tight cover removed, is shown in Figure 9.1B. The mounting box containing the computer interface is shown in Figure 9.1C. Most of the plug-in boards in this interface were custom designed on the project specifically for this polarizing radiometer, and were built using the facilities at the Davis campus. Some of these boards are shown in Figure 9.1D.

A schematic diagram applicable to either of the two channels of the instrument is shown in Figure 9.2. The light to be measured enters the collimator tube and passes successively through the rotating analyzer, variable bank of neutral density filters, and interference filter, and finally falls on the sensitive cathode of the photomultiplier tube. The photons impinging on the photocathode produce pulses in the photomultiplier output, the pulse rate being proportional to intensity of the incident light. This photon counting technique permits extremely high precision in the measurements, a feature which is required for measuring the small amount of elliptic polarization in the natural atmosphere.

In addition to the optical components mentioned, a retardation plate may be inserted at will into the optical system, thereby providing the possibility of measuring elliptic polarization, and an opaque shutter is inserted at regular intervals for measuring

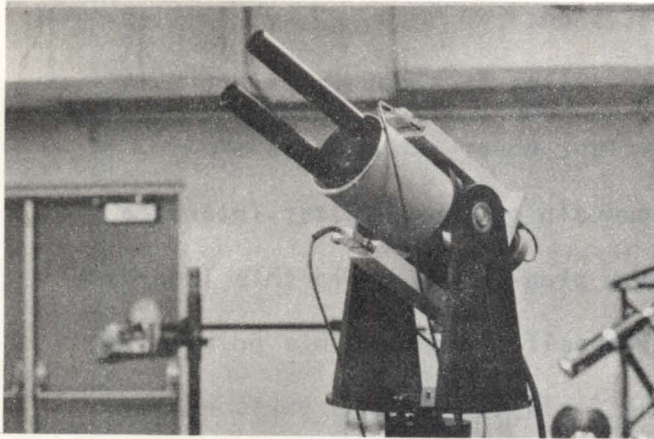


Figure 9.1A. The dual channel polarimeter (polarizing radiometer).

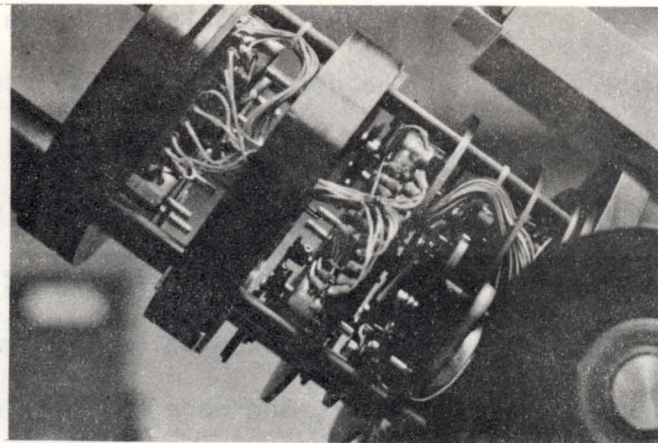


Figure 9.1B. Closeup view of the polarizing radiometer.

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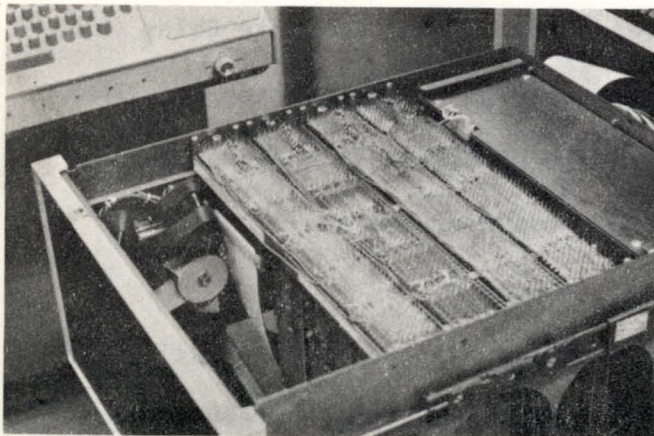


Figure 9.1C. Mounting box for computer interface.

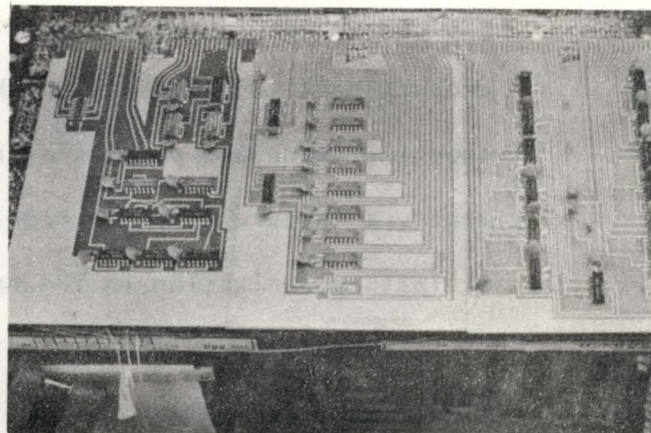


Figure 9.1D. Some of the custom boards for the interface.



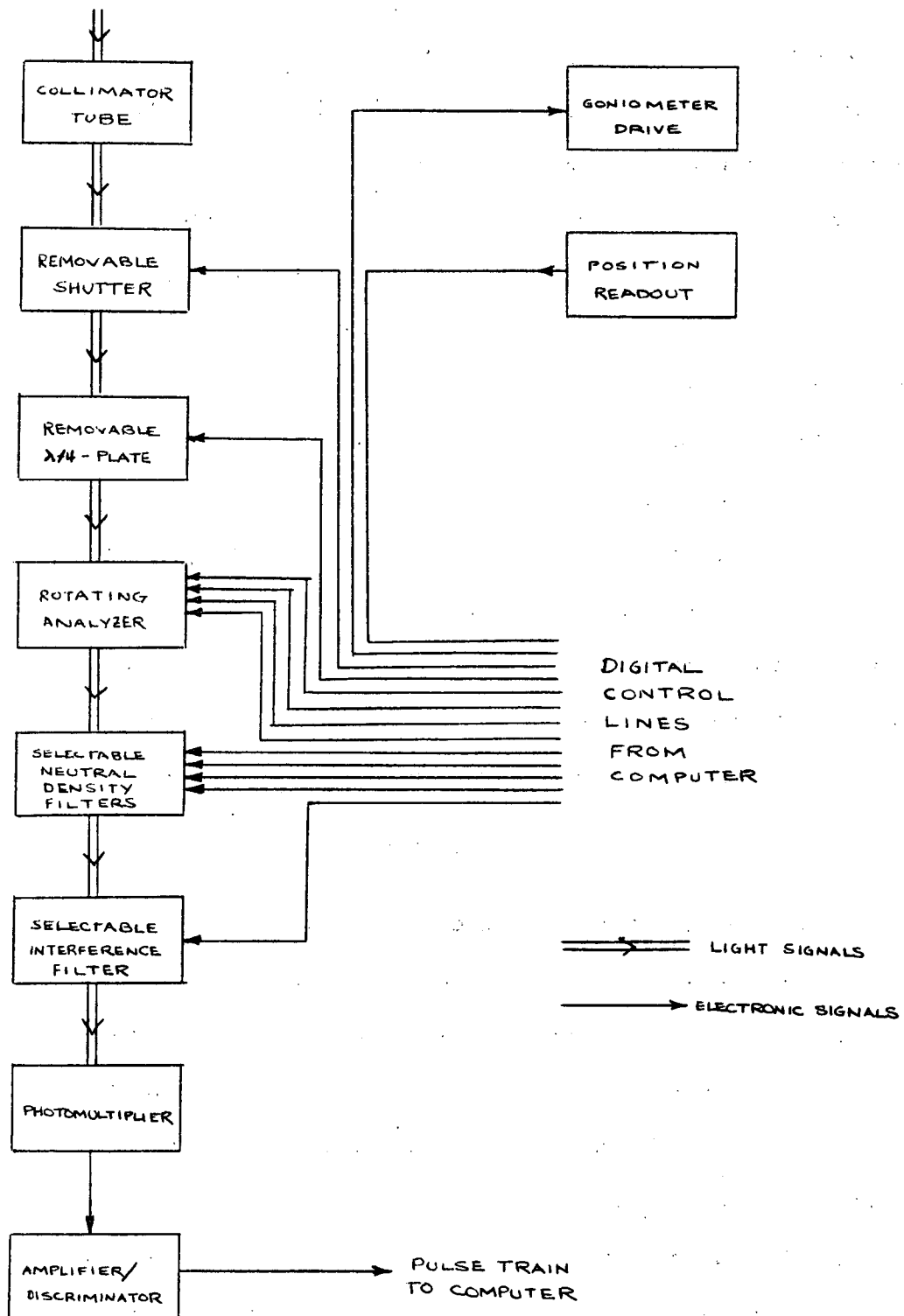


Figure 9.2 Schematic Diagram for the Dual Channel Polarizing Radiometer

the dark current of the system. Finally, provision is made for including at a future date a small source of polarized light for internal calibration of the instrument.

Each of the two channels is fitted with four interference filters, which provide a combined total of eight narrow wavelength intervals in the ultraviolet, visible, and near infrared portions of the spectrum. The two photomultiplier tubes (EMI6256A and EMI9559) were specially selected to cover this wide spectral interval and provide low noise for photon counting.

The output of the photomultipliers passes through a pair of SSRI Model 1120 Amplifier/Discriminators which produce a string of 10 nanosecond wide logic pulses. The rate of these pulses is proportional to the incident light level. The count rate may be corrected for pileup of pulses at high counting rates with the formula

$$N_o = (1 - \sqrt{1 - 4NT})/2T$$

where  $N$  is the measured count rate,  $N_o$  is the true count rate, and  $T = 25$  nanoseconds is the dead time of the amplifier/discriminator. The maximum measurable count rate from this formula is 20 Mhz, and the count rate due to dark count in the photomultipliers is typically about 1 kHz for both tubes. The dark count corresponds to  $5 \times 10^{-16}$  watts at 4000 Å, while the 20 Mhz count rate, with all neutral density filters in, corresponds to  $3 \times 10^{-7}$  watts. Thus, the dynamic range of the instrument is on the order of  $6 \times 10^8$ , which is at least two orders of magnitude more than is required for measuring sunlight in the atmosphere.

## 9.2. PRELIMINARY MEASUREMENTS

The dual-channel polarizing radiometer is currently being set up in an indoor laboratory to measure light reflected from natural surfaces in an environment where the illuminating source can be carefully controlled. Prior to this, some preliminary data were taken to indicate the quality of measurements available from the instrument. Some of those data are shown in Figures 9.3 through 9.5. Those diagrams represent measurements taken over a half-hour period from 4:30 p.m. to 5:00 p.m. with the instrument looking at a fixed spot in the sky  $15^{\circ}$  above the northern horizon. Each data point is reduced from a set of eight measurements of 1 second duration. The error bars indicated are derived from statistical errors in the measured count rates. The uncertainty in the measured intensity is approximately  $\pm 1.5\%$ , the uncertainty in the magnitude of the polarization is approximately  $\pm 0.002$ , and the uncertainty in the angle of the plane of polarization is about  $\pm 1^{\circ}$ .

## 9.3. TRANSFORMATION MATRIX FORMALISM

As is known, a beam of monochromatic light may be characterized by the vibrations of its electric (or magnetic) vector. Reflection and transmission processes may be treated as a transformation of the electric vector of the incident light into that of the reflected light. For extended sources and remote sensors, this transformation is characterized by a  $4 \times 4$  matrix  $T(\theta', \phi'; \theta, \phi)$ , where  $\theta, \phi$  define the direction of the incoming radiation and  $\theta', \phi'$  define the direction of the outgoing radiation. It follows that the trans-

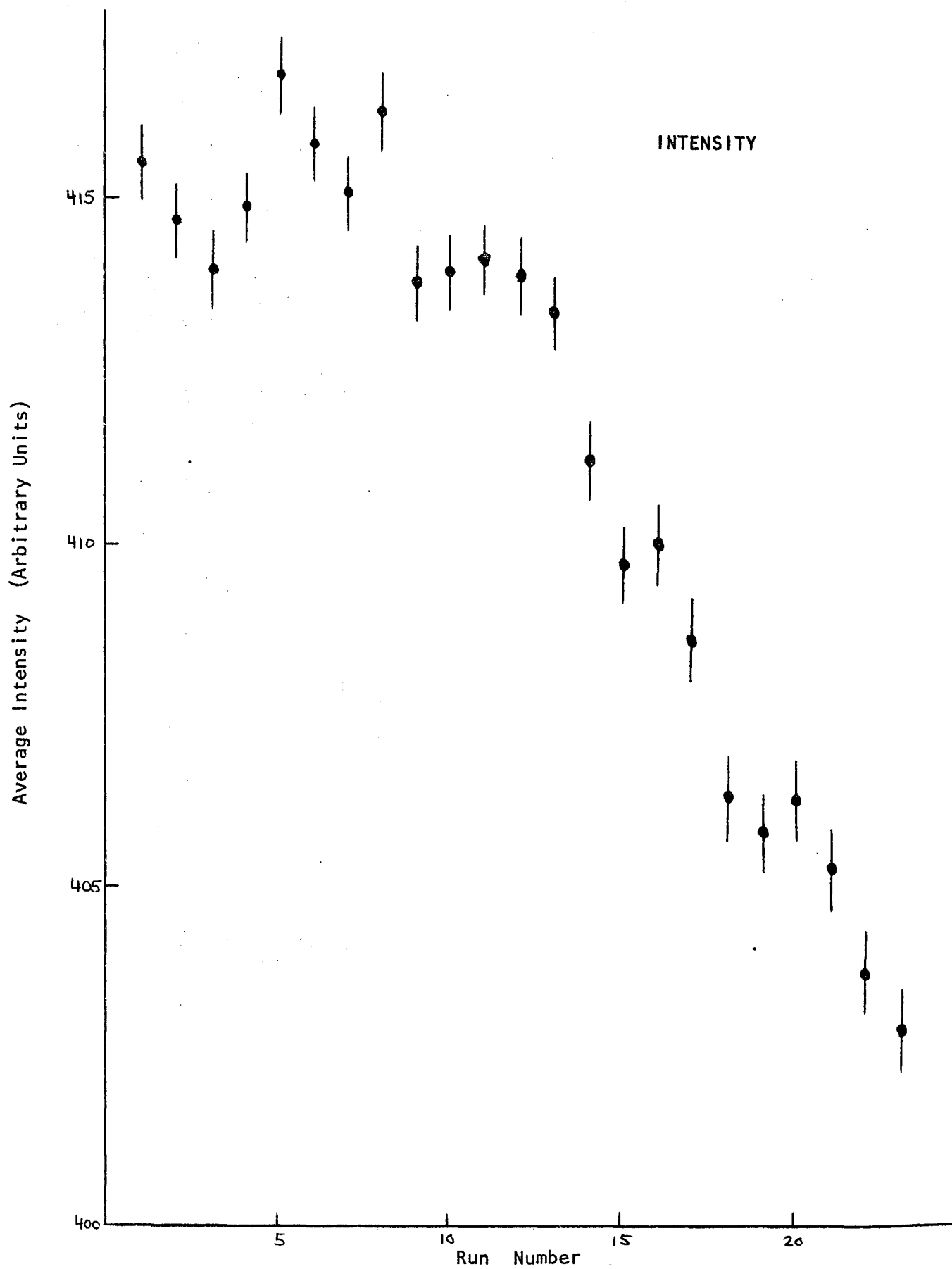


Figure 9.3 Preliminary Test Data from the Dual-Channel Polarizing Radiometer. (Part 1 of 3 parts, showing intensity of polarization.)

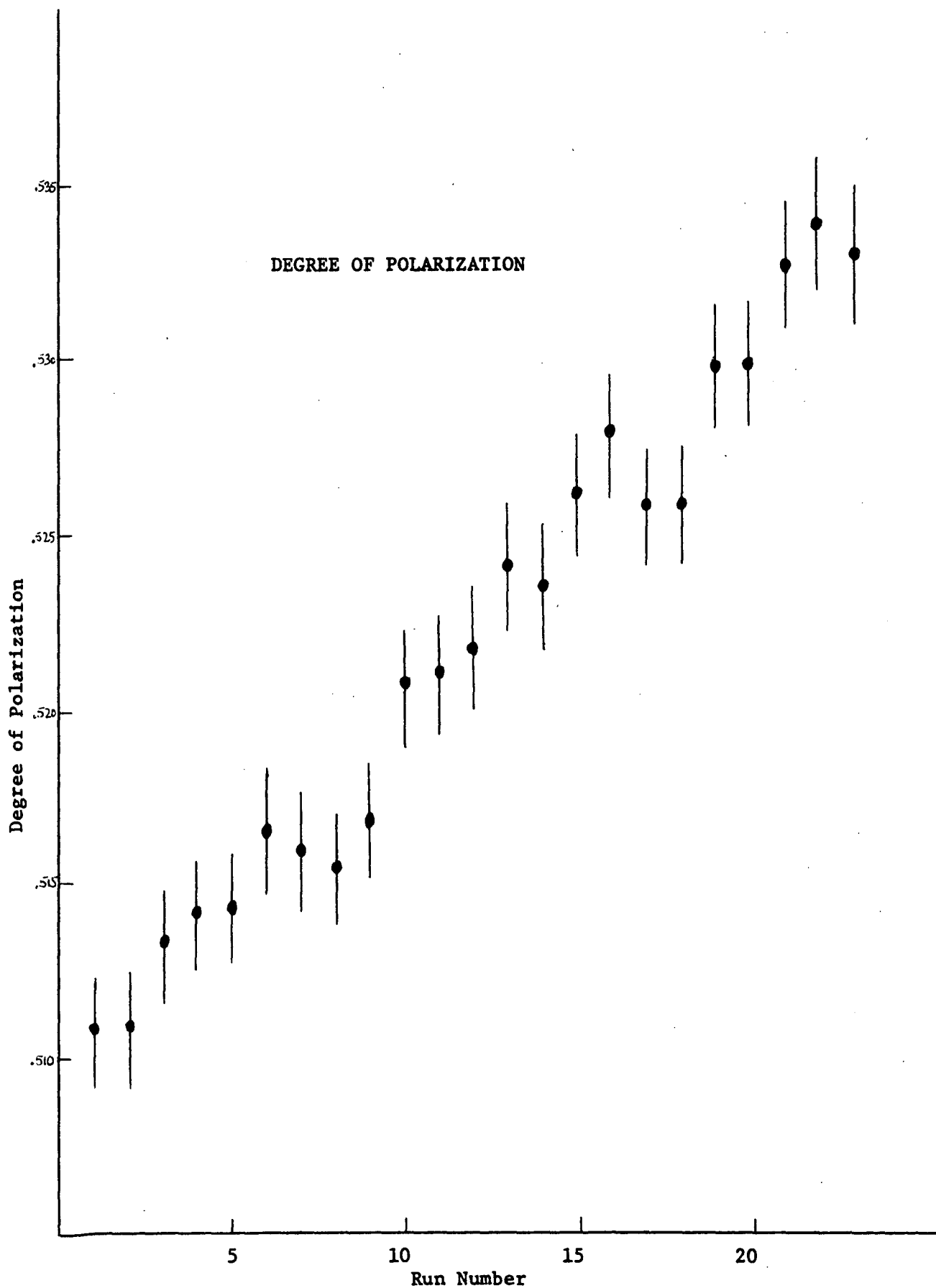


Figure 9.4 Preliminary Test Data for the Dual-Channel Polarizing Radiometer. (Part 2 of 3 parts, showing degree of polarization.)

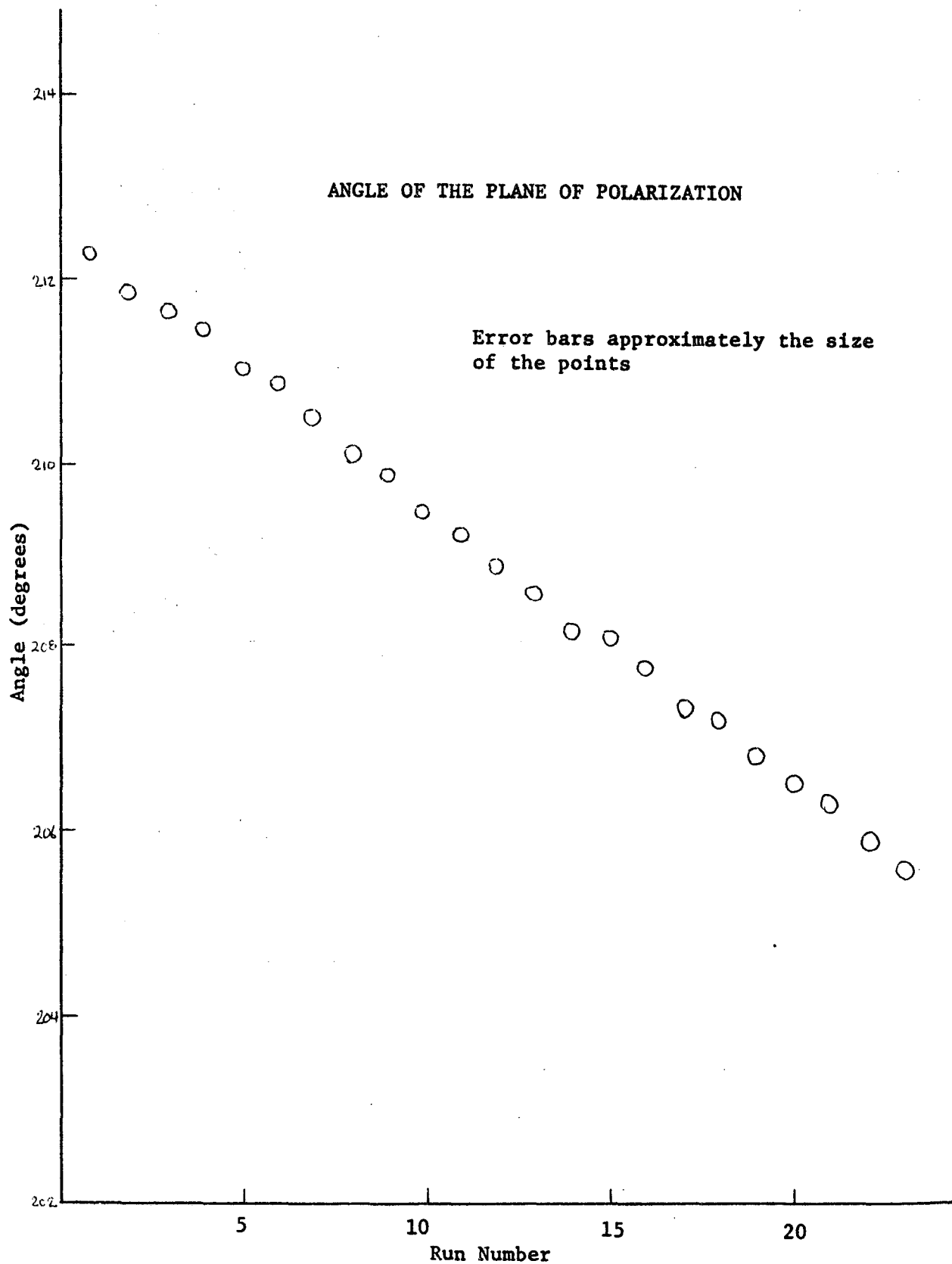


Figure 9.5 Preliminary Test Data for the Dual-Channel Polarizing Radiometer. (Part 3 of 3 parts showing angle of polarization.)

formation process can be described in terms of sixteen angular dependent parameters  $A_1, \dots, A_{16}$ . The angular dependence of these parameters can be written

$$A_i(\theta', \phi'; \theta, \phi) = \sum_{l, l', m, m'} a_{i, l l' m m'} Y_{lm}^*(\theta, \phi) Y_{l'm'}(\theta', \phi')$$

where the  $Y_{lm}$  are spherical harmonics. The coefficients  $a_{i, l l' m m'}$  completely characterize the transformation being studied. If, by careful laboratory and field measurements in conjunction with realistic models, the coefficients  $a_{i, l l' m m'}$  can be determined sufficiently well for the natural surfaces of interest and for typical atmospheres, then the image of the natural surface as seen by remote sensing techniques can be predicted. Once this is possible, optimization methods can be used to design the remote sensing experiment to be as effective as possible in distinguishing the features of interest.

#### 9.4 PHOTOGRAPHIC STUDIES

A collection of pairs of photographs has been taken of natural scenes with a polarizing lens in front of a 35mm camera. The orientation of the polarizer was always adjusted so that its plane of transmission was parallel to the plane of polarization of the incident light in one of the photographs and perpendicular to that plane in the other. The pair of slides shown in Figure 9.6 provides a good example of how polarizing optics, properly oriented, can enhance the detail of a distant natural surface. Details in the

NOT REPRODUCIBLE



Figure 9.6A. Typical scene with plane of polarizer normal to plane of polarization of incident light.



Figure 9.6B. Typical scene with plane of polarizer parallel to plane of polarization of incident light.



mountain range are much clearer in the photo for which the polarizer minimized the effect of light scattered between mountain and camera.

## 9.5 ATMOSPHERIC MODELING

A major computer program has been written for computing the effects of haze, dust, clouds, and other aerosol particles on the radiation field in the atmosphere. Such particles are always present in the real atmosphere, and their effect is always in the direction of a degradation of images transferred through the atmosphere. By a parametric analysis performed with the computer program it will be possible to estimate the extent of image degradation under various atmospheric conditions, to identify the parameters of greatest importance in producing image degradation, and, hopefully, to derive methods for minimizing such adverse effects under realistic atmospheric situations.

The program is based on a solution to the equation of radiative transfer by the "doubling method." This method was chosen from among several others because of its ability to take into account multiple scattering of light by the atmospheric aerosols in a manner which is conservative of computer time. Because of this feature it will be possible to study the effects of a relatively large number of aerosol models without excessive expense for the computer.

## 9.6 TASKS FOR THE COMING YEAR

### 9.6.1 Experimental Measurements

The experimental effort for the coming year will be devoted mainly to the characterization of reflection from natural surfaces.

The first step will be to determine the matrix elements for some natural surfaces indoors where the illuminating source can be carefully controlled. This study will also give useful information about the total information content in the transformation matrix characterizing different natural surfaces. When the matrices characterizing different surfaces have been satisfactorily determined, they will be used to predict what would be seen with those same surfaces outdoors. By using the polarizing radiometer to measure the distribution of incident light over the hemisphere of the sky,  $I(\theta, \phi)$ , and integrating the transformation matrix over the solid angle  $d\Omega = d\cos\theta d\phi$ , the reflected light can be estimated to be

$$I'(\theta', \phi') = \int d\Omega \cdot T(\theta', \phi'; \theta, \phi) I(\theta, \phi)$$

where the transformation matrix  $T$  contains the elements mentioned above. At this point, the instrument will be used to measure the reflection from the surfaces in their natural setting to evaluate the prediction. If the predicted values are actually observed, then we can use the method with confidence in obtaining complete reflection signatures of natural surfaces for remote sensing purposes. If, however, there are significant discrepancies between the predicted and observed values, it will be necessary to resolve the discrepancies in order to bring the full power of the method to bear on the problems of remotely sensing the environment.

### 9.6.2 Aircraft Mounting of Instrument

In order to utilize the instrument for measurements in a realistic configuration for remote sensing, it is very desirable that the instrument be mounted on an aircraft. Preliminary contacts have been made with NASA Goddard (Dr. Warren Hovis) about the possibility of mounting it in the NASA research aircraft Convair 990. There appears to be no basic problem in either the administration or hardware for the mount, but the details will have to be worked out. It is expected that this will be accomplished in the coming period.

### 9.6.3 Atmospheric Modeling

A number of different atmospheric models will be studied from a theoretical standpoint to predict how well images of surface features will be transmitted under different atmospheric conditions. This work will prepare the way for a physical interpretation of the radiation fields to be eventually observed with the polarizing radiometer aboard the aircraft. The computations will include all of the Stokes parameters, thereby yielding the maximum amount of information contained in the radiation field. By combining the calculations for model atmospheres with the results of reflection measurements, the images to be seen through the atmosphere can be predicted. Finally, the validity of the entire method can be evaluated (in a future period) by comparing the predicted images with those obtained experimentally from the aircraft.

#### 9.6.4 Photography with Polarized Light

The acquisition of photographs showing polarization effects will continue throughout the next year. Some of these photographs will be used by Dr. Algazi as test cases for digitization. The polarization parameters are, in some cases, a good indicator of water pollutants such as oil spills. Photographic studies will be made of such effects.

## Chapter 10

### SUMMARY AND CONCLUSIONS

Each of the preceding chapters has adequately summarized work done during the period covered by this report by the individual investigative groups who have been participating in our integrated study. Likewise, the preceding chapters have adequately set forth the conclusions that have been derived from their aspects of the study during this reporting period. Consequently, our concluding chapter will not restate such information. Rather it will seek to relate progress made on our overall project, to broader issues governing the usefulness of remote sensing data to the management of California's earth resources.

A concluding chapter in our last previous report on this project, dated 1 May 1971, dealt with the dynamics of earth resource management in California and elsewhere. In that chapter several specific and highly current examples were given to document the fact that California, as a corollary to its being the most populous of the 50 states (and to its being one of the most rapidly growing regions in the world), offers a preview of what is soon to come elsewhere throughout the United States, and eventually throughout much of the globe. In those examples it was shown that there is a mix of many kinds of problems relating to proper resource management, ranging from ecological and technological, through political and social, and including economic, legal and even enforcement aspects.

During the interim, we have closely followed each of the developments

that were dealt with in that chapter, together with several others that have since come to the fore. Only a few of these will be commented upon in this section, by way of providing an update to our earlier report.

#### 10.1 WATER FROM THE CALIFORNIA WATER PROJECT IS NOW BEING PUMPED OVER THE TEHACHAPI MOUNTAINS FOR DELIVERY TO CONSUMERS IN SOUTHERN CALIFORNIA, EVEN AS SOME POLITICIANS AND OTHER CRITICS ARE CONTINUING TO SAY THAT THIS WHOLE PROJECT IS A \$3 BILLION MISTAKE

Some critics of the California Water Project continue to maintain that the most limiting resource in Southern California is not water but air; therefore, they say, until such time as we can find a cure for the acute problem of atmospheric pollution in the Los Angeles Basin, we should not encourage more people to move to that area by providing resources such as water to accommodate their needs. Instead, we should encourage some of the people already there to leave, by withholding water from them. Other critics, including at least one Nobel Laureate, maintain that even at the present time water could be provided more cheaply to Southern California by desalting the nearby ocean than by transporting the water from Northern to Southern California. Still other critics are mainly concerned with damage which might be done to the Sacramento River Delta Region and even to the biota of San Francisco Bay by construction of the "Peripheral Canal". This part of the master plan for the California Water Project would prevent water produced in Northern California from circulating through the Delta Region enroute to Southern California. Some critics are prepared to admit that the overall benefits of the California Water Project (including added protection against potential flood increased capabilities for producing hydroelectric power, possibilities for increased agricultural production, and opportunities to provide

increased recreational services to California's residents) make the project eminently worthwhile. While such gracious concessions might seem to leave them with little to criticize, they concentrate their criticism on the assertion that the rapidity with which Southern Californians would need water from Northern California was grossly overestimated.

As mentioned in Chapter 1 of our present report, much of this criticism has been levelled at decision makers in California's Administrative Branch. Much of it also appears to be unwarranted. There is increasing evidence that remote sensing techniques of the type which our group is developing will be useful in portraying, more clearly than has ever been possible before, certain types of information which are highly relevant to the management of California's water resources. In this way much of the unwarranted criticism should be alleviated, and solutions to such problems as may be the subject of warranted criticism, more readily found. An increased realization of these promising possibilities helps to account for the increased degree of cooperation being achieved between our scientists and those of the California Administrative Branch. The achieving of such cooperation is so central to the success of our integrated study that two examples of it will be given here: (1) Last April our group submitted to NASA a proposal entitled, "An Integrated Study of Earth Resources in the State of California Based on ERTS-A and Supporting Aircraft Data". At that time, California's Lt. Governor Reinecke, in commenting upon our proposal in his letter to NASA authorities stated:

"On behalf of the State of California, I wish to take this opportunity to strongly endorse this proposal. The basic research which under this proposal would be performed by a highly competent group of University of California scientists, would yield valuable information through which better resource

management data, so valuable and important to our rapidly developing state, could be utilized. As further evidence that the State of California is vitally interested in using ERTS type data in resource management, a second proposal (which will indicate quantity and recommended locations from which ground truth data will be provided) will be submitted to NASA directly from my office on behalf of the administrative branch of the State of California. This second proposal entitled, 'A State of California Study Combining Basic Research and Applied Use of ERTS-A Data for More Effective Resources Management', is being prepared in close cooperation with scientists of the University of California and is complementary rather than competitive with the University's proposal...Mr. Norman B. Livermore, Secretary-Resources Agency, and Mr. Earl Coke, Secretary-Agriculture and Services Agency, who represent the largest segments of state government utilizing this data, and who have contributed guidance and impetus to the proposed program, will provide further leadership and assistance as required."

(2) At the time of this writing plans are being completed for a series of training courses which will be taught in part primarily by scientists from our 6-campus project and which will be attended primarily by scientists from California's Administrative Branch who seek to learn, prior to the launch of ERTS-A, how they can most effectively use data of the type which ERTS-A will provide the better to manage California's natural resources. The first of these courses will be presented in March, 1972.

#### 10.2 ACTION IS NOW BEING TAKEN TO MINIMIZE THE PROSPECT THAT CALIFORNIA'S WATER WILL BE POLLUTED THROUGH THE SPILLAGE OF OIL AND OTHER CONTAMINANTS

The Environmental Protection Agency of the federal government is funding a series of studies to determine the extent to which aerial photography and other forms of remote sensing might be used to detect potential sources of these contaminants or (to use the words of EPA), "potential spill sources". While national and perhaps even global objectives are among those governing this study, all of the sites being



investigated at present are in California. Hence, the immediate and direct applicability of findings of these continuing studies, particularly with reference to our own studies of California's water resources, and indeed of its entire resource complex, will prompt us to continue monitoring the EPA studies very closely.

### 10.3 CONCERN OVER PERSONAL ATTITUDES AND LAND USE DEVELOPMENTAL TRENDS IN THE WEST SIDE OF THE SAN JOAQUIN VALLEY HAS PROMPTED STUDIES TO BE MADE OF THAT AREA THAT ARE COMPLEMENTARY TO OURS IN MANY RESPECTS

Notable among the studies that are closely related to ours is one that has just been completed by Leslie W. Senger, dealing with factors governing land use and developmental patterns in the West Side, San Joaquin Valley Area of California, now that water is being made available to that region through the California Water Project. The written report of his findings has just been accepted as satisfying the requirements for a doctoral dissertation from the University of California, with emphasis on geography. Highly central to his study is an evaluation of the factors that govern man's decisions on how land in any developing area (such as the West Side of the San Joaquin Valley) will be used, both regionally and on a parcel-by-parcel basis. It has been widely believed, as a result of publications by Horvath and other geographers, that the main categories of factors ordinarily involved in any such decisions were economic, technological, cultural, psychological and social. Senger has masterfully demonstrated that this widely-held concept exhibits important deficiencies when applied to developmental trends which he has observed on the West Side of the San Joaquin Valley. The increased understanding which his study provides, permits us to categorize much more

intelligently the relevant kinds of information which we can derive from a study of remote sensing data obtained of that rapidly developing area. As with most other aspects of our study, this type of "progress" is of importance not merely in relation to the development of California's resources but also to the eventual development of similar resources in parts of the globe which presently are far less developed than California.

#### 10.4 MUCH OF CALIFORNIA'S SCIENTIFIC AND INDUSTRIAL COMMUNITY IS LOOKING FORWARD ENTHUSIASTICALLY TO THE ERTS-A EXPERIMENT

As the date when ERTS-A is to be launched draws near, there is increasing evidence that it will be quite generally regarded by scientists and resource managers in California as "the greatest photographic experiment in history". Many have already asked NASA for permission to observe the launch of ERTS-A from Vandenburg Air Force Base. In 33 counties of California, agricultural agents have asked to be party to our proposed ERTS-A experiment. Mention already has been made of the increased interest in that experiment by state government officials, from the governor's office down to the resource managers, themselves. Several federal government agencies of both the Department of Agriculture and the Department of Interior, through their California State offices, likewise wish to participate in, or observe closely, our proposed ERTS-A experiment.

This situation produces in our research group a sense of both high exhilaration and sober responsibility as we contemplate the role which we may be privileged to play during the entire period that ERTS-A is expected to be functional. It also provides us with unusually high motivation as we study, during this interim period, the simulated ERTS-A imagery that currently is being flown for us under the NASA U-2 aircraft program.